The Journal of Bone and Joint Surgery

The Official Publication of
The American Orthopaedic Association
The British Orthopaedic Association
The American Academy of Orthopaedic Surgeons
The Australian Orthopaedic Association
The Canadian Orthopaedic Association
American Society for Surgery of the Hand
New Zealand Orthopaedic Association
South African Orthopaedic Association
Western Orthopedic Association

SEPTEMBER 1960

American Volume
Vol. 42-A, No. 6

8 THE FENWAY, BOSTON 15, MASSACHUSETTS, U. S. A.
BRITISH OFFICE:
82 PORTLAND PLACE, LONDON, W. 1, ENGLAND

The Journal of Bone and Joint Surgery

PUBLISHED IN TWO VOLUMES

WILLIAM A. ROGERS, *Editor-in-Chief Emeritus*

AMERICAN VOLUME

Editor and Chairman Board of Editors: THORNTON BROWN

American Board of Associate Editors

LENOX D. BAKER, Durham, North Carolina
WILLIAM H. BICKEL, Rochester, Minnesota
JOSEPH H. BOYES, Los Angeles, California
CRAWFORD J. CAMPBELL, Albany, New York
JOE B. DAVIS, Portland, Oregon
ALBERT B. FERGUSON, JR., Pittsburgh, Pennsylvania
CHARLES H. FRANTZ, Grand Rapids, Michigan
DAVID S. GRICE, Philadelphia, Pennsylvania
CHARLES H. HERNDON, Cleveland, Ohio
JOHN WILLIAM HILLMAN, Nashville, Tennessee
FLOYD H. JERGESEN, San Francisco, California
EMANUEL B. KAPLAN, New York, N. Y.
WILLIAM A. LARMON, Chicago, Illinois
WILLIAM R. MACAUSLAND, JR., Boston, Massachusetts
PAUL E. MCMASTER, Beverly Hills, California
JOHN H. MOE, Minneapolis, Minnesota
JOHN ROYAL MOORE, Philadelphia, Pennsylvania
JESSE T. NICHOLSON, Philadelphia, Pennsylvania
FRED C. REYNOLDS, St. Louis, Missouri
DANIEL C. RIORDAN, New Orleans, Louisiana
WAYNE O. SOUTHWICK, New Haven, Connecticut
LEE RAMSAY STRAUB, New York, N. Y.
JACK K. WICKSTROM, New Orleans, Louisiana

BRITISH VOLUME

SIR REGINALD WATSON-JONES, *Editor*

British Editorial Board

SIR WALTER MERCER, *Chairman*
H. JACKSON BURROWS, *Deputy Editor*
J. CRAWFORD ADAMS, *Assistant Editor*
W. D. COLTART, *Treasurer*
C. E. L. ALLEN, Cape Town, South Africa
ROLAND BARNES, Glasgow, Scotland
J. S. BATCHELOR, London, England
JOHN CHARNLEY, Manchester, England
F. P. DEWAR, Toronto, Canada
J. KENNEDY ELLIOTT, Wellington, New Zealand
A. L. EYRE-BROOK, Bristol, England
T. J. FAIRBANK, Cambridge, England
ROGER GARIÉPY, Montreal, Canada
B. KEON-COHEN, Melbourne, Australia
DOUGLAS PARKER, Hobart, Tasmania
R. G. PULVERTAFT, Derby, England
ROBERT ROAF, Oswestry, England
H. J. SEDDON, London, England
E. W. SOMERVILLE, Oxford, England
GORONWY THOMAS, Liverpool, England
O. J. VAUGHAN-JACKSON, London, England

Corresponding Editors

Argentina: JOSÉ VALLS
Austria: WALTHER EHALT
Belgium: JEAN VERBRUGGE
Brazil: F. E. GODOY MOREIRA
Cuba: ALBERTO INCLÁN
Denmark: JOHANNES MORTENS
Finland: K. E. KALLIO
France: R. MERLE D'AUBIGNÉ
Germany: MATHIAS HACKENBROCH
Italy: O. SCAGLIETTI
Japan: EISHI KONDO
Mexico: JUAN FARILL
Netherlands: J. D. MULDER
Poland: ADAM GRUCA
Portugal: ARNALDO RODO
Sweden: STEN FRIBERG
Uruguay: JOSÉ LUIS BADO

Committees

THE JOURNAL OF BONE AND JOINT SURGERY, INCORPORATED

The American Orthopaedic Association

The American Academy of Orthopaedic Surgeons

BOARD OF TRUSTEES

DAVID M. BOSWORTH, *Chairman*
KEENE O. HALDEMAN, *Vice-Chairman*
H. RELTON MCCARROLL, *Treasurer*
JOSEPH A. FREIBERG, *Secretary*
THORNTON BROWN, *Editor*
R. BEVERLY RANEY
H. HERMAN YOUNG

American Society for Surgery of the Hand
President: DANIEL C. RIORDAN
President-Elect: GEORGE S. PHALEN
Secretary-Treasurer: DON L. EYLER
1919 Hayes Street, Nashville 4, Tennessee

The Australian Orthopaedic Association
W. L. MACDONALD, *President*
R. MCKELLAR HALL, *President-Elect*
A. I. RHYDDERCH, *Editorial Secretary*
RICHARD HODGKINSON, *Secretary*, 135 Marquarie Street, Sydney, New South Wales

The British Orthopaedic Association
H. J. SEDDON, *President*
SIR REGINALD WATSON-JONES, *Editor*
E. W. SOMERVILLE, *Editorial Secretary*
J. CRAWFORD ADAMS, *Secretary*
47 Lincoln's Inn Fields, London, W.C. 2

The Canadian Orthopaedic Association
W. B. MACKINNON, Winnipeg, *President*
W. W. OLLERHEAD, London, *Vice-President*
IAN W. DAVIDSON, *Secretary-Treasurer*
130 Elm Street, Sudbury, Ontario
F. P. DEWAR, *Editorial Secretary*
706 Medical Arts Building, Toronto, Ontario

New Zealand Orthopaedic Association
H. WALDEN FITZGERALD, Dunedin, *President*
ALAN ALLRED, Dunedin, *Secretary-Treasurer*
N. NISBET, *Editorial Secretary*
Dunedin Hospital, Dunedin, C.1, New Zealand

South African Orthopaedic Association
R. C. J. HILL, *President*
N. M. THOMPSON, *Treasurer*
CYRIL KAPLAN, *Secretary*, 71 Trust Building, Gardiner Street, Durban, South Africa

Western Orthopedic Association
President: FRASER MACPHERSON
President-Elect: MARVIN P. KNIGHT
Secretary: WALTER F. CARPENTER
2850 Sixth Avenue, San Diego 3, California

Published in the United States by The Journal of Bone and Joint Surgery, Incorporated

Published in the United Kingdom for The British Editorial Society of Bone & Joint Surgery by E. & S. Livingstone, Teviot Place, Edinburgh

THE JOURNAL OF BONE AND JOINT SURGERY

American Office
8 The Fenway, Boston 15, Massachusetts, U.S.A.
Managing Editor: John A. Reed
Assistant Editor: H. Stephen Tilton

British Office
82 Portland Place, London, W. 1, England
Editorial Secretary: Jean Barnes

The Journal of Bone and Joint Surgery*

American Volume

TABLE OF CONTENTS

September 1960

PAGE

Electromyographic Study of Transplanted Muscles about the Knee in Poliomyelitic Patients.
By *David H. Sutherland, M.D., Frederic C. Bost, M.D.,* and *Edwin R. Schottstaedt, M.D.,* San Francisco, California 919

Tetracycline Fluorescence in Bone Lesions. Preoperative Tetracycline Administration for the Identification of Abnormal Tissue during Operation and Tetracycline Concentration in Certain Bone Lesions.
By *John F. McLeay, M.D.,* and *Benedict R. Walske, M.D.,* Omaha, Nebraska 940

Prolonged Tourniquet Ischemia of Extremities. An Experimental Study on Dogs.
By *Francis X. Paletta, M.D., Vallee Willman, M.D.,* and *Arthur G. Ship, M.D.,* St. Louis, Missouri 945

Surgery of the Hand in Cerebral Palsy and the Swan-Neck Deformity.
By *Alfred B. Swanson, M.D.,* Grand Rapids, Michigan 951

Attempted Treatment of Scoliosis by Unilateral Vertebral Epiphyseal Arrest.
By *H. R. McCarroll, M.D.,* and *William Costen, M.D.,* St. Louis, Missouri 965

Eosinophilic Granuloma of Bone. A Study of Twenty-eight Cases.
By *Malcolm H. McGavran, M.D.,* and *Herbert A. Spady, M.D.,* St. Louis, Missouri 979

The Pathogenesis of Dupuytren's Contracture. Experimental and Further Clinical Observations.
By *Robert D. Larsen, M.D., Nahoto Takagishi, M.D.,* and *Joseph L. Posch, M.D.,* Detroit, Michigan 993

Amino-Acid Chromatography and Transaminase Activity in Denervation Atrophy.
By *Pinckney J. Harman, Ph.D.,* Jersey City, New Jersey, and *J. L. Magnani, Ph.D., S. D. Sanwal, M.D.,* and *W. A. L. Thompson, M.D.,* New York, N. Y. 1008

Opposition of the Thumb and Its Restoration.
By *Bernard Jacobs, M.D.,* and *T. Campbell Thompson, M.D.,* New York, N. Y. 1015

Transposition of the Compressed Spinal Cord in Kyphoscoliotic Patients with Neurological Deficit.
By *R. C. Schneider, M.D.,* Ann Arbor, Michigan 1027

Malignant Disease of the Extremities Treated by Exarticulation. Analysis of Two Hundred and Sixty-four Cases with Survival Rates.
By *James B. Troup, M.D.,* and *William H. Bickel, M.D.,* Rochester, Minnesota 1041

Volar Transnavicular Perilunar Dislocation of the Carpus.
By *Alexander P. Aitken, M.D.,* and *Edward A. Nalebuff, M.D.,* Boston, Massachusetts 1051

(Continued on page 3)

The Journal of Bone and Joint Surgery (American Volume) is issued eight times a year—in January, March, April, June, July, September, October, and December. The 1960 subscription price, payable in advance, is $14.50. Single copies $3.00.

The Journal of Bone and Joint Surgery, second-class postage paid at Boston, Mass. and at additional mailing offices. Editorial and business offices, 8 The Fenway, Boston, Mass. Accepted at the special rate of postage provided for in the act of February 28, 1925, Paragraph 4, Section 412, Postal Laws and Regulations; authorized April 21, 1932. Additional entry at Concord, New Hampshire, authorized June 10, 1947.

Copyright 1960 by *The Journal of Bone and Joint Surgery, Incorporated*

* TITLE REGISTERED IN UNITED STATES PATENT OFFICE

Dear Subscriber:

There is so much "family feeling" between The Journal and its subscribers that we are going to ask your help in a family problem.

We maintain our own subscription records. Every new subscription, renewal, change of address, order for back issues, inquiry, and complaint goes through the hands of a staff who almost know the subscriber files by heart. This is perhaps old-fashioned but we believe it results in better service than would any impersonal, mechanized system.

The natural busy time for the subscription department is the end of the year because most renewals start in January. This is right and proper.

This is our sad story —

The peak load of the subscription department continues through January, February, March and into April because of the *extra* work caused by renewals that come in late, that is, that are received after an issue has been missed. It takes more than three times as much time and bookkeeping to take a name off the lists and put it back as it does to record a prompt renewal. It is also frustrating work because you undo on Tuesday what you did on Monday.

Please send your renewal check early!

Thank you

1961 Subscription Prices

The Journal of Bone and Joint Surgery

American Volume $14.50

Eight Issues

January	July
March	September
April	October
June	December

British Volume $7.50

Four Issues

February	August
May	November

Both Volumes $22.00

Twelve Issues

All Single Issues $3.00
All Back Issues $3.00

Subscriptions and Renewals to Both Volumes may be sent to either

The Journal of
Bone and Joint Surgery
8 The Fenway
Boston 15, Massachusetts

or

The British Society of
Bone and Joint Surgery
82 Portland Place
London W.1, England

Sterling prices
American Volume £5.4.0
British Volume £2.13.6

TABLE OF CONTENTS

(Continued from page 1)

PAGE

Duplication of Hypothenar Muscles Simulating Soft-Tissue Tumor of the Hand. Report of a Case.
By *Paul R. Lipscomb, M.D.*, Rochester, Minnesota 1058

Extra-Articular Hip Arthrodesis. Salvage Procedure for Persistent Pain Following Replacement Arthroplasty: A Case Report.
By *S. S. Coleman, M.D.*, and *W. S. Hunter, M.D.*, Salt Lake City, Utah 1062

Malignant Bone Tumors in Siblings. Ewing's Tumor and an Unusual Tumor Perhaps a Variant of Ewing's Tumor. A Case Report.
By *Robert W. Huntington, M.D., Donald J. Sheffel, M.D., Mortimer Iger, M.D.*, and *Charles Henkelmann, M.D.*, Bakersfield, California 1065

Unilateral Laminar Joints of Lumbar Spine. Case Report.
By *Malcolm D. Jones, M.D.*, Montreal, Quebec, Canada 1076

Slipped Capital Femoral Epiphysis in Negroes. A Study of Ninety-five Cases.
By *Caesar Orofino, M.D., John J. Innes, M.D.*, and *Cedric W. Lowrey, M.D.*, New Orleans, Louisiana 1079

A Rare Subperiosteal Metastasis Eroding the Femoral Cortex Eight Years after Radical Mastectomy for Adenocarcinoma.
By *Captain Charles A. Borgia*, Medical Corps, United States Air Force 1084

Granulomatous Tenosynovitis Due to Beryllium. Histological and Spectrographic Analysis. A Case Report.
By *E. D. Vere Nicoll, M.D.*, and *Eugene A. Foster, M.D.*, Charlottesville, Virginia 1087

The Electrical Response of Human Skeletal Muscle to Passive Stretch.
By *Robert O. Becker, M.D.*, Syracuse, New York 1091

The Exchange Fellows 1104

Proceedings:
The Virginia State Orthopaedic Society 1105

Corrections 1108

News Notes 1109

Addresses of Contributors 1110

List of Advertisers ..... Adv. 61

Notes to Contributors ..... Cover III

Subscription Rates for 1960

American Volume, $14.50
Published January, March, April, June, July, September, October, December

British Volume, $7.50
Published February, May, August, November

All subscription rates include postage.

Checks should be made payable to *The Journal of Bone and Joint Surgery, Inc.*

Microfilms of the American Volumes are available to regular subscribers through University Microfilms, 313 North First Street, Ann Arbor, Michigan

Although it is intended that all advertising material accepted conforms to ethical medical standards, acceptance does not imply endorsement by *The Journal.*

THE JOURNAL OF BONE AND JOINT SURGERY

American Office
8 The Fenway, Boston 15, Massachusetts, U. S. A.

British Office
82 Portland Place, London, W. 1, England

CAMP
HIP ABDUCTION PILLOW
effective therapy at home

An abduction pillow splint is a practical, atraumatic method for gradually obtaining hip abduction in infants with abduction contractures, unilateral or bilateral hip dysplasia and many cases of congenital dislocation. It is also an effective means of maintaining abduction following more severe dislocations requiring rigid immobilization or surgery. This type of pillow splint is well tolerated, permits the child to sit or stand while maintaining the abduction position.

In addition to the Camp regular Frejka type pillow this new, improved Camp pillow splint fits the contour of the legs to bring the child to froglike position. Adjustable for leg size; a plastic water resistant pillow held in a pocket of the bib; crossed adjustable shoulder straps, all with gripper snap fasteners for easy application. Bib is made of a soft attractive cotton fabric and extra bibs are available for use while one is being laundered. This permits treatment without interruption.

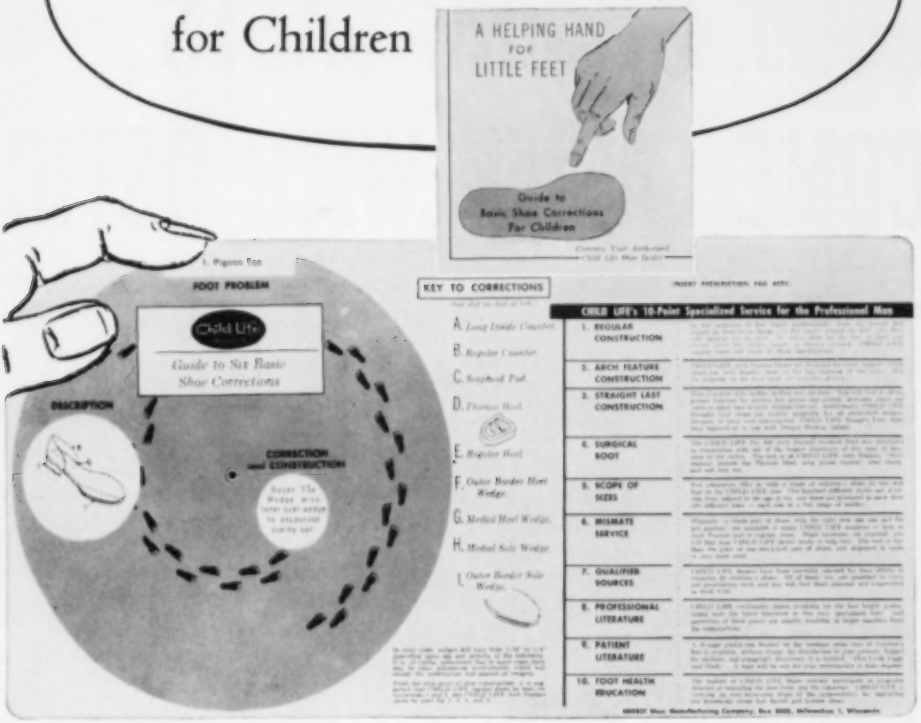
Three sizes (pillow width between legs) —Small 6″, Medium 9″, Large 12″.

S. H. CAMP & COMPANY, JACKSON, MICHIGAN

S. H. Camp & Company of Canada, Ltd., Trenton, Ontario

In answering advertisements, please mention *The Journal of Bone and Joint Surgery.*

This is for YOU — doctor
a Guide to Basic Shoe Corrections for Children



The advantages of this new Guide are practical, and they are visual. You see at a glance everything that is involved. Just dial the problem . . . and you automatically receive a diagrammatic description of the correct wedging procedure with a capsule explanation of the correction.

You'll find this a valuable time-saver, a helpful, handy reference to have in your files . . . and it's yours for the asking. Send for your copy now via a note from your secretary, or return the coupon which has been placed here for your convenience.

Herbst Shoe Manufacturing Company*
P.O. Box 2005 • Milwaukee 1, Wisconsin

**Makers of Child Life Shoes for more than 35 years. One of America's great sources of juvenile footwear, both in correction and regular construction.*

Herbst Shoe Manufacturing Company
P.O. Box 2005, Milwaukee 1, Wisconsin

Gentlemen:

Please send on for my use and that of my office associates ___ copies of your Guide to Basic Shoe Corrections for Children.

Name _____

Address _____

City _____ Zone _____ State _____

In answering advertisements, please mention *The Journal of Bone and Joint Surgery*.

Why do specialists use OSTIC plaster bandages in orthopedic teaching centers?

GOOD, STRONG CASTS COME EASIER WITH OSTIC

All day, every day—OSTIC is creamy, gentle, never gritty

OSTIC is consistent. Every time you open the package you know you're going to get the same solid results you had with the last one.

Strong, fast and precise, OSTIC delivers at least 97% of the original plaster to the cast. You have two setting times: Fast (5 to 9 min.) and Extra-Fast (2 to 5 min.).

OSTIC plaster casts stand up under most any kind of wear, even with rambunctious little patients. For an all-around, everyday bandage that is always easy on your hands, trust OSTIC plaster bandages.

Individual, airtight OSTIC packages prevent pre-setting. Plaster stays fresh indefinitely

Curity®
OSTIC®
PLASTER BANDAGES

THE KENDALL COMPANY
BAUER & BLACK
DIVISION

In answering advertisements, please mention *The Journal of Bone and Joint Surgery.*

Hanger Offers CERTIFIED Prosthetic Facilities and Technicians in 37 Cities

37 HANGER offices throughout the United States have been approved by the American Board for Certification as "Certified Prosthetic Facilities." Each office offers one or more Prosthetic Applicance Technicians approved by the ABC as "Certified Prosthetists". These are more "certified" facilities and technicians than offered by any other manufacturer.

The ABC is an important service to both the amputee and the doctor. Its avowed objective, when organized by the industry in 1948, was to guarantee the public the highest competency in the prosthetic appliance profession. As a result of extensive cooperation from the medical profession, great strides have been made. Today three of the seven directors are named by the American Academy of Orthopaedic Surgeons (the story of this unique program was described in the Journal of the AMA, May 10, 1952). In only a few years, the Board has made the seal illustrated a mark of merit for Prosthetic Facilities and Prosthetists alike.

A "Certified Prosthetist" has become a person of tested ability and proved experience. No certificate is awarded without a comprehensive written and oral examination of the technician by qualified Board members, including orthopedic doctors. His qualifications, experience, and skills are given thorough scrutiny. "Certified Facility" demands not only that the physical facilities, but the personnel, be of sufficiently high calibre to guarantee a result that will satisfy the industry and the doctor alike.

HANGER has been a leader in the Certification program — the first to institute an internal program to ensure the Certification of all HANGER Technicians. Today HANGER offers Certified Facilities and Certified Prosthetists throughout the country. This plus HANGER'S complete line of arm and leg appliances for all types of amputations, and the Nationwide Service Network through the HANGER Service Card, guarantees every doctor an excellent chance for the successful rehabilitation of his amputee patients. Any HANGER office will be glad to render information or service without obligation.

Hanger PROSTHETICS

AVAILABLE AT AUTHORIZED FACILITIES IN THE FOLLOWING CITIES:

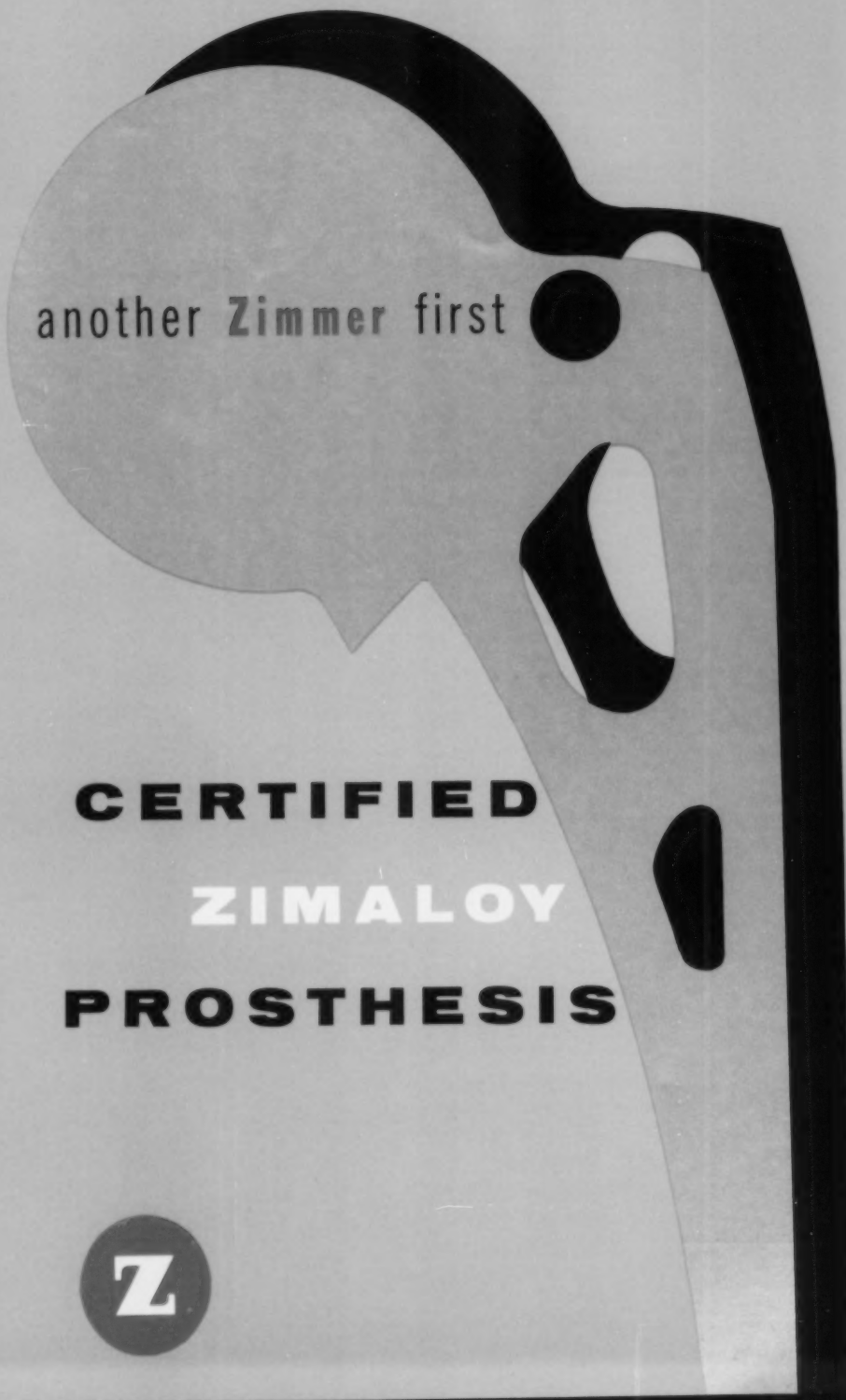
Eastern Region:
BALTIMORE 1, MD.
BOSTON 15, MASS.
CHARLESTON 2, W. VA.
NEW YORK 11, N. Y.
PHILADELPHIA 7, PA.
RALEIGH, N. C.
RICHMOND 19, VA.
ROANOKE 12, VA.
WASHINGTON 13, D. C.

Midwestern Region:
CHICAGO 5, ILL.
CINCINNATI 29, OHIO
DALLAS 1, TEXAS
EVANSVILLE, IND.
FORT WAYNE, IND.
HOUSTON, TEXAS
INDIANAPOLIS 2, IND.
OKLAHOMA CITY 3, OKLA.
PEORIA 4, ILL.
ST. LOUIS 66, MO.
WICHITA, KANS.

Central Region:
COLUMBUS 8, OHIO
JOHNSTOWN, PA.
PITTSBURGH 1, PA.

Southeastern Region:
ATLANTA 9, GA.
BIRMINGHAM 1, ALA.
COLUMBIA 5, S. C.
JACKSONVILLE, FLA.
MIAMI 37, FLA.
MOBILE, ALA.
MONTGOMERY, ALA.
NASHVILLE 5, TENN.
NEW ORLEANS 19, LA.
ORLANDO, FLA.
SAVANNAH, GA.
ST. PETERSBURG, FLA.
TAMPA 2, FLA.
WEST PALM BEACH, FLA.

In answering advertisements, please mention *The Journal of Bone and Joint Surgery.*


another Zimmer first
CERTIFIED
ZIMALOY
PROSTHESIS
Z

CERTIFIED PROSTHESIS BY ZIMMER

Model: Moore Type
Serial No. G 395
(Certification for Thompson type available)

Material: Zimaloy
(Cobalt-Chromium-Molybdenum Alloy)

Quality Control:

1. Each casting is X-rayed for internal soundness.
2. A notarized Material Certification is furnished by supplier. This certification which covers the chemical and mechanical test results of the metal, also certifies 100% X-ray and Zyglo Pentrex testing.
3. Each Zimaloy prosthesis undergoes a Non-destructive Mechanical Test. The Moore Type is subjected to a standard direct load of 5,500 lbs. This standard load is safely below the elastic limits and does not weaken a sound prosthesis. If the prosthesis is unable to withstand this load a downward curve will develop on the chart which will indicate a weakness or defect.
4. A Zyglo bath is performed to detect surface flaws or defects not visible to the eye.
5. Each head is gaged for correct diameter.
6. Each prosthesis is visually inspected before being approved and sent to the stock room.

Certified Permanent Record:

Each Moore Type prosthesis is etched with a permanent serial number which appears on its X-ray, the Material Certification, the mechanical test graph, and the final inspection report. There is a permanent record kept of each prosthesis which contains the certifications listed above. At any time in the near or distant future this record can be produced showing the date that the prosthesis was manufactured, the X-ray and all of the other certifications of its satisfactory quality. This is truly a prosthesis with a pedigree, another Zimmer first.

Test No. ..... Size ..... Area ..... Yield Point Lbs. Sq. In. ..... Ultimate Str. Lbs. Sq. In. .....

Elongation / Compression { In. ..... Inches ..... Per Cent. Elongation ..... Per Cent. Reduced Area ..... Date .....

LOAD IN POUNDS

0 1,250 2,500 3,750 5,000

G381
G382
G383
G384
G385
G386
G387
G388
G389
G390
G391
G392
G393
G394
G395
G396
G397

0 1,250 2,500 3,750 5,000

G398
G399
G400
G401
G402
G403
G404
G405
G406
G407
G408
G409
G410

1 3/4" 4005 1-8-60
Tested To 5500#

MATERIAL CERTIFICATION

TO: Zimmer Mfg. Co.
Warsaw, Indiana

DATE: December 30, 1959

ATT:

MATERIAL SPECIFICATION	CUSTOMER ORDER NO.	PART NO.	DATE SHIPPED	QUANTITY SHIPPED	PACKING SLIP NO.
Zimalloy	C 6731	4005-1-3/4" Moore Pros. Shank	12/30/59	30	3457-385-F

CHEMICAL ANALYSIS

Serial No. G381 through G410

MASTER HEAT NO. A250 LOT NO. 1613

C	Si	Mn	P	S	Cr	Ni	Fe	Mo						
.27	.51	.63	.010	.014	27.52	1.86	.32	6.53						

TEST RESULTS

ULTIMATE STRENGTH PSI	YIELD STRENGTH PSI	% ELONGATION	% RED. OF AREA	HARDNESS
127,300	76,380	10.0	10.3	30.5

XRAY 100% MAGNAFLUX Not Required ZYGLO -Pentrex 100%

Remarks: As Cast

Chicago Spectro Service Laboratory, Inc.

WE CERTIFY THAT THE PARTS CONTAINED IN THIS SHIPMENT HAVE BEEN FABRICATED TO CONFORM TO YOUR SPECIFICATION AS NOTED

Subscribed and sworn to before me
this 30 day of December, 19 59

Glendale D. Hite
Notary Public

My commission expires Feb 4, 1963

By H. J. Zabalka
H. J. Zabalka, Chief Met.

No. 9840A

ZIMMER MANUFACTURING COMPANY

MATERIAL DISPOSITION AND INSPECTION REPORT

DATE:	INSPECTION: Zyglo ( ) OUTSIDE PROCESSING ( ) FINAL (X) RECEIVING ( ) LINE ( )	PART NAME AND NUMBER	ENG. CHANGE
2-24-60			
PUR. ORDER NO. C 6731		#4005 1-3/4" Moore type Prostheses	

VENDOR: ADDRESS:
Zimmer Mfg. Co., Warsaw, Indiana

RECEIVING REPORT NO.	P.O. NO.	QUAN. RECEIVED	QUAN. INSPECTED	QUAN. DEFECTIVE
		30	30	None

30 pcs. of the following serial numbers have been delivered to the shipping department. All castings have passed mechanical test, radiographic, Zyglo, and visual examination. Certification of chemical analysis of material used is on file and conforms to engineering specifications.

G381 G382 G383 G384 G385 G386 G387 G388 G389 G390 G391 G392
G393 G394 G395 G396 G397 G398 G399 G400 G401 G402 G403 G404
G405 G406 G407 G408 G409 G410

INSTRUCTIONS AND REMARKS:

DISPOSITION						APPROVAL		INSPECTOR
ACCEPT	REJECT	RETURN	SCRAP	MAT. REVIEW	SALVAGE	INSP.	ENG.	
30								

CC:MDIR
#4005

ZIMMER MFG. CO.
QUALITY CONTROL DEPT.

ZIMMER MANUFACTURING CO.
Warsaw, Indiana, U.S.A.

Proven

in over five years of clinical use and
more than 750 published clinical studies

Effective

for relief of anxiety and tension

Outstandingly Safe

- simple dosage schedule produces rapid, reliable tranquilization without unpredictable excitation
- no cumulative effects, thus no need for difficult dosage readjustments
- does not produce ataxia, change in appetite or libido
- does not produce depression, Parkinson-like symptoms, jaundice or agranulocytosis
- does not impair mental efficiency or normal behavior

Miltown®

meprobamate (Wallace)

Usual dosage: One or two 400 mg. tablets t.i.d.
Supplied: 400 mg. scored tablets, 200 mg. sugar-coated tablets; or as MEPROTABS®—400 mg. *unmarked*, coated tablets.

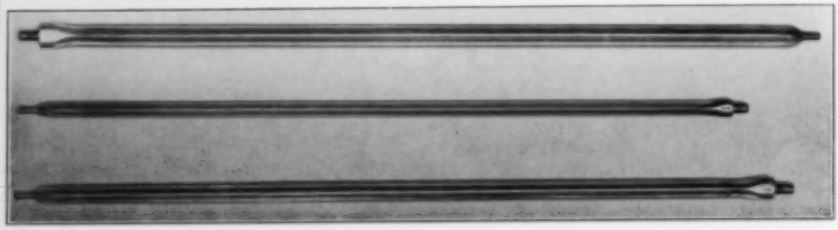
04-2056

WALLACE LABORATORIES / *New Brunswick, N. J.*

®TRADE-MARK

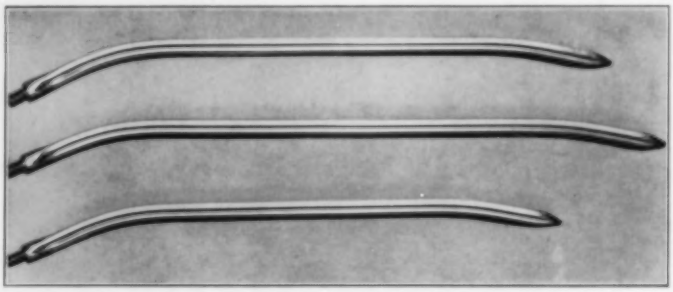
In answering advertisements, please mention *The Journal of Bone and Joint Surgery.*

LOTTES NAILS and INSTRUMENTS

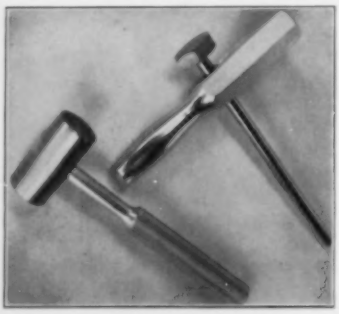


***LOTTES* FEMORAL NAILS** are manufactured with diameters of 3/8, 7/16, and 1/2 inches —with lengths in 1/2 inch variations from 14 to 20 inches.

***LOTTES* TIBIAL NAILS** are made in 5/16 and 3/8 inch diameters—in lengths from 9 to 15 1/2 inches, in variation of 1/2 inch.



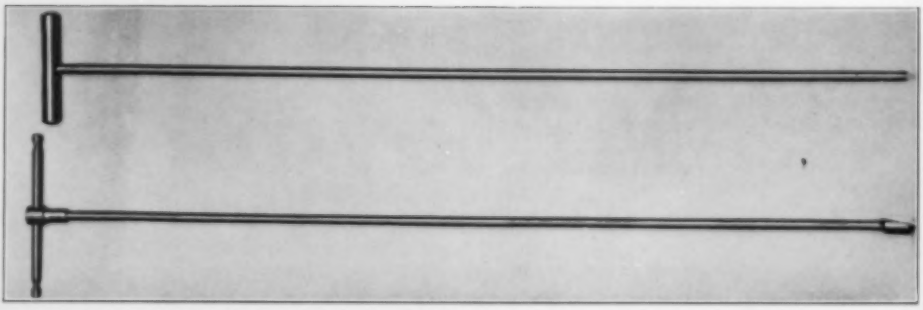
***LOTTES* NAILS AND INSTRUMENTS ARE MADE OF 18-8 SMo STAINLESS STEEL**



***LOTTES* DRIVER-EXTRACTOR COMBINATION and *LOTTES* MALLET**

***LOTTES* GUIDE WIRE AND *LOTTES* REAMER**

The reamer comes in 3 diameters: 3/8, 7/16, and 1/2 inch—all are 23 inches in length.



CHAS. A. SCHMIDT SURGICAL INSTRUMENT COMPANY

3689 Olive Street, Saint Louis 8, Missouri

even if your patient is a whip snapper*

he'll soon be riding high again, thanks to

PARAFON®

(PARAFLEX® + TYLENOL®)

for muscle relaxation plus analgesia

in arthritis

PARAFON®

with Prednisolone

McNEIL McNeil Laboratories, Inc.
Philadelphia 32, Pa.

prescribe PARAFON in low back pain—sprains—strains—rheumatic pains

Each PARAFON tablet contains:

PARAFLEX® Chlorzoxazone† ..... 125 mg.
The low dosage skeletal muscle relaxant

TYLENOL® Acetaminophen ..... 300 mg.
The superior analgesic in musculoskeletal pain

Dosage: Two tablets t.i.d. or q.i.d.

Supplied: Tablets, scored, pink, bottles of 50.

Each PARAFON with Prednisolone tablet contains: PARAFLEX® Chlorzoxazone† 125 mg., TYLENOL® Acetaminophen 300 mg., and prednisolone 1.0 mg.

Supplied: Tablets, scored, buff colored, bottles of 36.

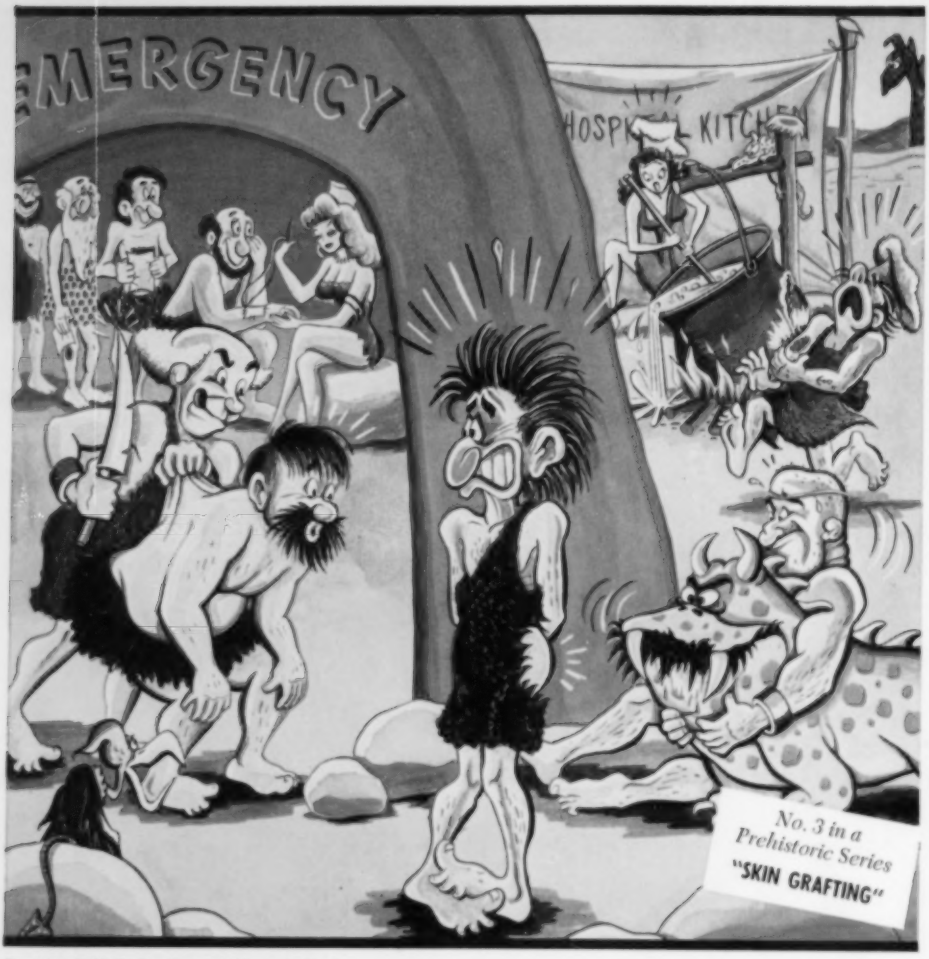
Dosage: One to two tablets t.i.d. or q.i.d.

Precautions: The precautions and contraindications that apply to all steroids should be kept in mind when prescribing PARAFON with Prednisolone.

*tailman on hook-and-ladder fire engine

†U.S. Patent No. 2,895,877

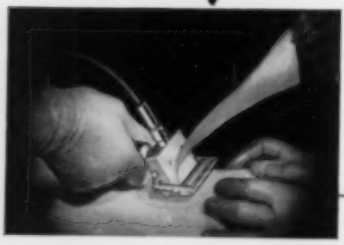
316A60



Reprints suitable for framing available upon request

Stryker **Today's concept in skin grafting . . .**

ROLO-DERMATOME



This modern, power operated Dermatome feels well balanced in your hand. Only the disposable blade oscillates to cut accurate grafts set by a single lever, from 5/1000 to 30/1000. Adjustable widths – 1½, 2¾ and 3 inches. Rollers flatten the skin to eliminate tension as skin comes in contact with the blade.

Always available on 30 day trial.

Stryker

SURGICAL AND HOSPITAL EQUIPMENT

Orthopedic Frame Company

420 ALCOTT STREET • KALAMAZOO, MICHIGAN

specific treatment for arthritic joints

intra-articular/intrasynovial/intrabursal instillation

□ **good to excellent response in a vast majority of patients**—"Low doses...provided rapid and effective relief...in almost all of the 157 patients treated..."[1] "...appeared to be superior as an intra-articular injectable substance to anything hitherto available."[2]

□ **provides sustained, long lasting benefits**—In 28 out of 34 patients,"...complete relief was provided by a single injection...the relief lasting for an average of more than 2.5 months."[2]

□ **rapid relief of pain, swelling, and improved range of motion**—"Pain was relieved in 3 or 4 days, or less..."[3] "...marked improvement in range of motion occurred in all of these patients."[3] "...more potent, milligram for milligram, than other injectable corticosteroids."[4]

□ **undesirable side reactions outstandingly rare**—"...appears to be a safe, potent, and effective preparation..."[5] "...tolerated as well as or better than hydrocortisone or prednisolone."[6]

Dosage: usual doses—2.5 to 5.0 mg. for smaller joints; 5.0 to 15.0 mg. for larger joints. *Side Effects:* outstandingly rare; although systemic effects do not ordinarily occur with Kenalog Parenteral when the proper techniques and dosages are used, careful clinical supervision is advisable for all patients receiving steroid therapy. *Contraindications:* infections in or near joints—e.g., gonococcal or tuberculous arthritis. *Supply:* a sterile aqueous suspension in 5 cc. vials, each cc. providing 10 mg. triamcinolone acetonide. *References:* 1. Sperling, I. L.: Clinical Research Notes vol. 3, No. 1 (Jan.) 1960. 2. Steinberg, C. L.: op. cit. 3. Urist, M. R.: op. cit. 4. Meltzer, L. E.: op. cit. 5. Schwartz, S.: op. cit. 6. Felts, W. R.: op. cit.

Among 363 patients treated with Kenalog Parenteral, 315 (86.7%) obtained complete relief or were markedly improved.[1-6]

new **Kenalog Parenteral**

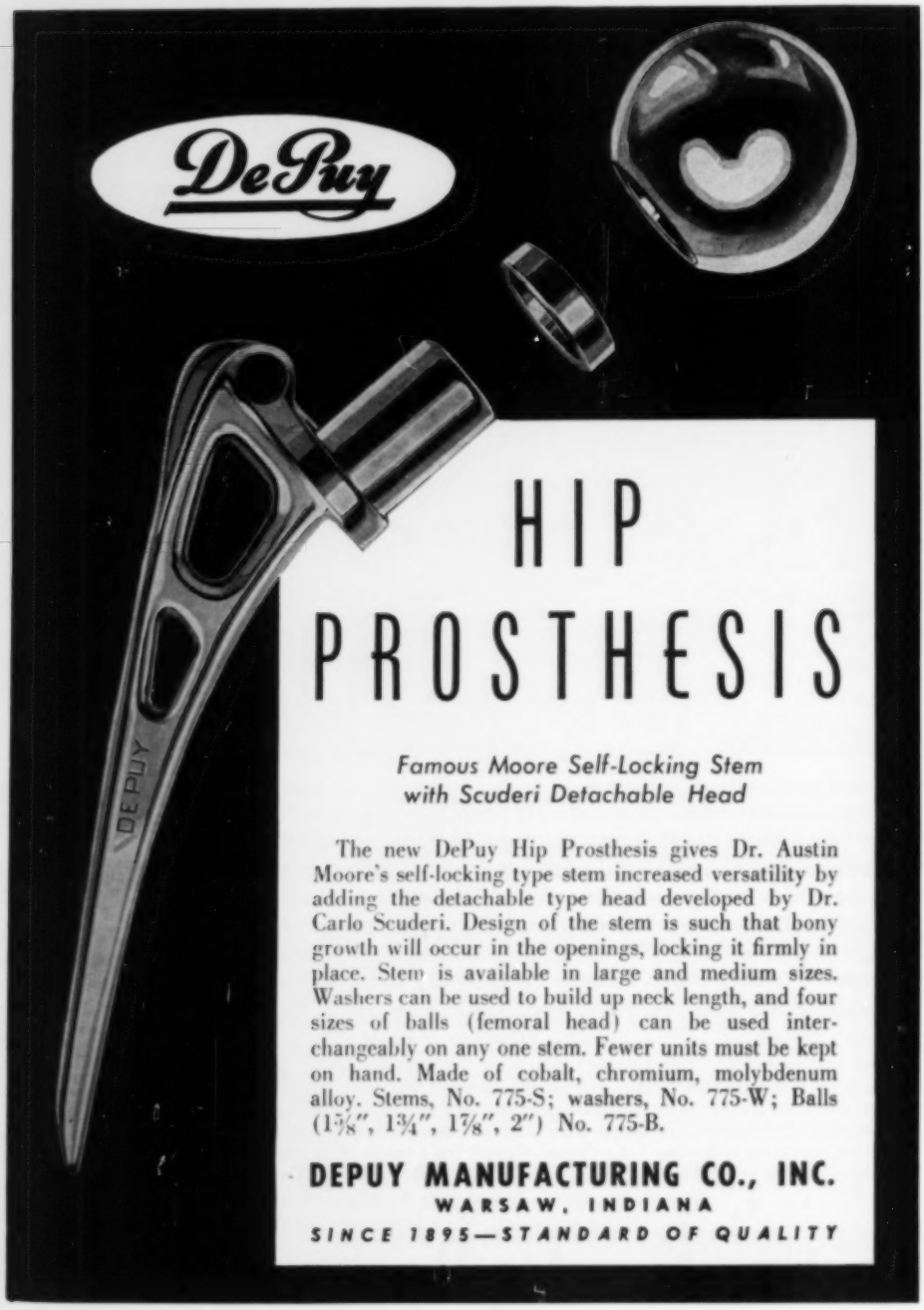
Squibb Triamcinolone Acetonide Aqueous Suspension

"KENALOG"® IS A SQUIBB TRADEMARK.

SQUIBB

Squibb Quality—the Priceless Ingredient

NEW



HIP PROSTHESIS

Famous Moore Self-Locking Stem with Scuderi Detachable Head

The new DePuy Hip Prosthesis gives Dr. Austin Moore's self-locking type stem increased versatility by adding the detachable type head developed by Dr. Carlo Scuderi. Design of the stem is such that bony growth will occur in the openings, locking it firmly in place. Stem is available in large and medium sizes. Washers can be used to build up neck length, and four sizes of balls (femoral head) can be used interchangeably on any one stem. Fewer units must be kept on hand. Made of cobalt, chromium, molybdenum alloy. Stems, No. 775-S; washers, No. 775-W; Balls (1⅝", 1¾", 1⅞", 2") No. 775-B.

DEPUY MANUFACTURING CO., INC.
WARSAW, INDIANA
SINCE 1895—STANDARD OF QUALITY

**NO SPRAIN,
NO STRAIN,
NO LOW
BACK PAIN**

RELA™ RELAXES, EASES ACUTE MUSCLE SPASM & PAIN X

CARISOPRODOL

RELA achieves the necessary interruption of the spasm/pain cycle through its unique twofold myogesic[X] action.

RELA restores mobility by relieving stiffness, pain and spasm.

Bibliography: 1. Ostrowski, J. P.: Orthopedics **2**:7 (Jan.) 1960. **2.** Kestler, O. C.: J.A.M.A. **171**:2039 (April 30) 1960. **3.** Frankel, K.: Paper presented at Scientific Meeting, New York State Society of Industrial Medicine, Inc., New York, Sept. 30, 1959.

Schering

M-295

[X]**MYOGESIC:** MUSCLE RELAXANT ANALGESIC

Is femoral head replacement advantageous?

Limited originally to salvage procedures, replacement arthroplasty has become increasingly important in the last decade, and is now in many indications regarded as the operation of choice. Many hundreds of case reports clearly define the advantages of hip arthroplasty. [1-12]

"The replacement prosthesis has a very definite place in surgery of the arthritic hip, especially when the head of the femur is essentially gone or inadequate."[9]

In the past 5 or 6 years the well-established criteria for replacement arthroplasty have been notably expanded to include refractory rheumatoid- and osteoarthritides. Femoral head replacements in these conditions offer great promise in those individuals where crippling is severe, or where drug therapy does not seem to facilitate ambulation. Clinical results of numerous hip arthroplasties in rheumatoid- and osteoarthritides have proved highly gratifying both immediately and after lengthy follow-up. [2-8]

Aside from shorter hospital stays, hip arthroplasty offers additional advantages in that secondary surgical procedures are seldom required, nursing care is eased, and the economic burden of the patient is thus reduced. Moreover, prosthetic surgery of the hip affords earlier and more complete ambulation, freedom from pain and limp in most cases, and by providing an almost "normal" hip, enables these patients quickly to return to an active, useful life. [1, 11, 13-20]

Indications:

- Rheumatoid arthritis
- Acute fractures in the aged
- Un-united, long-term fractures
- Delayed non-union
- Acute unstable fracture (Pauwels' 3)
- Osteoarthritis
- Aseptic and avascular necrosis
- Bilateral ankylosis
- Salvage
- Pathologic fractures

REFERENCES: 1. Beegel, P. M.: J. Maine M. A. 49:86, 1958. 2. Moore, A. T.: J. Bone & Joint Surg. 39A:811, 1957. 3. Symposium on Femoral Head Replacement Prostheses, J. Bone & Joint Surg. 38A:407, 1956. 4. Stinchfield, F. E. et al.: J. Bone & Joint Surg. 39A:1043, 1957. 5. Thompson, F. R.: J. Bone & Joint Surg. 36A:489, 1954. 6. Moore, A. T.: South. M. J. 45:1015, 1952. 7. Gaenslen, F. G.: Wisconsin Med. J. 59:181, 1960. 8. Moore, A. T.: In Acad. Orthop. Surg. Instructional Course Lectures, vol. 16, C. V. Mosby, 1959, p. 309. 9. Aufranc, O. E.: Med. Forum, Mod. Med. 27:33, 1959. 10. Thompson, F. R.: In Acad. Orthop. Surg. Instructional Course Lectures, vol. 16, C. V. Mosby, 1959, p. 299. 11. Savastano, A. A., et al.: Rhode Island Med. J. 41:425, 1958. 12. Day, P. L. and Hinchey, J. J.: Clin. Orthop., No. 6, p. 27, 1955. 13. Breck, L. W.: Southwestern Med. 35:207, 1954. 14. Hart, G. M.: J. Lancet 78:369, 1958. 15. Peterson, L. T. and Raad, M. A.: Med. Ann. D. C. 24:233, 1955. 16. Carlander, L. W.: Minnesota Med. 42:566, 1959. 17. Mahoney, J. W. et al.: Am. J. Surg. 95:577, 1958. 18. Barker W. E.: Manitoba Med. Rev. 38:673, 1958. 19. Matchett, F.: Rocky Mountain Med. J. 56:47, 1959. 20. Bascom, J. et al.: J.A.M.A. 169:1863, 1959.

Osteoarthritic hip of long standing.

The F. R. Thompson Hip Prothesis in situ.

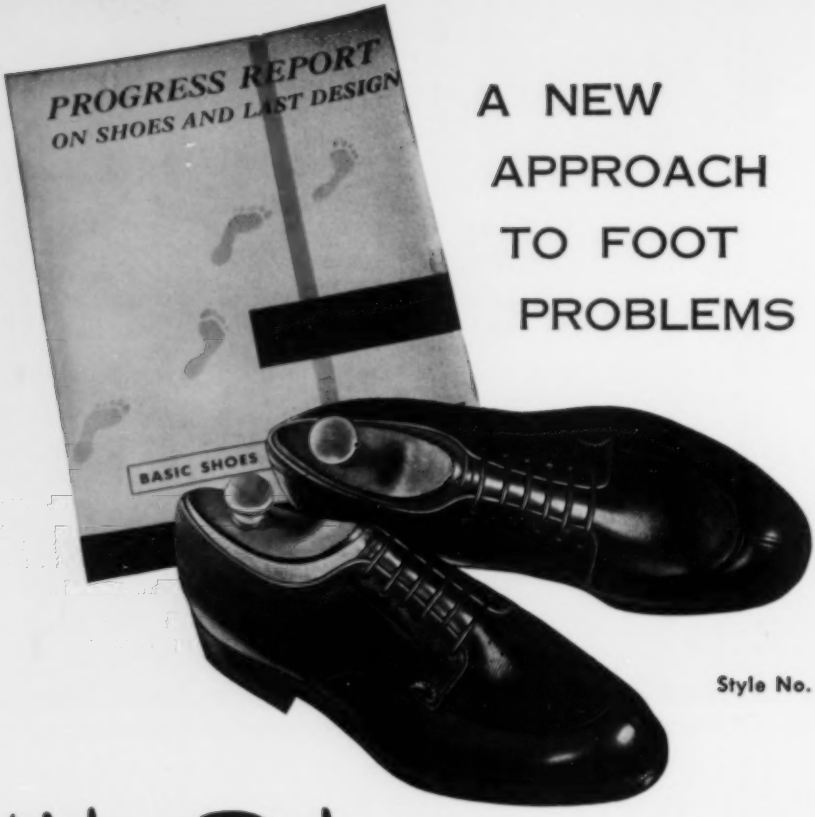
"Artificial prostheses for replacement of the upper end of the femur deserve a place in our armamentarium of treatment of hip disease...At this stage...the prosthesis has come of age..."[7]

The F. R. Thompson Intramedullary Hip Prosthesis, Catalog No. 6936, is available in head diameters from 1½" - 2¼", in ⅛" increments. For F. R. Thompson instruments, please consult your Austenal catalog, section III, page 7.

VITALLIUM®

Surgical Appliances

AUSTENAL COMPANY SURGICAL PRODUCTS
DIVISION OF HOWE SOUND COMPANY 224 EAST 39th STREET, NEW YORK 16, N.Y.



A NEW APPROACH TO FOOT PROBLEMS

Style No. 84

Alden-Pedic SCIENTIFIC CONSTRUCTION SHOES

Preferred by the Nation's Leading Foot-Fitting Specialists

- Long inside counter
- Right and left ortho heels, long inside
- Heavy gauge right and left ribbed steel shank.
- New "Depth Design" accommodates prescribed corrections

WRITE FOR BOOKLET AND NAME OF NEAREST DEALER

Alden-Pedic lasts and shoes serve 3 purposes:

- **Fit the individual foot shape . . .**
- **Accommodate your prescribed corrections . . .**
- **Provide a stable, controlled foundation.**

Write us today for our new illustrated brochure of Alden-Pedic styles for men and boys and our new "Progress Report on Shoe and Last Design."

C.H. ALDEN SHOE COMPANY

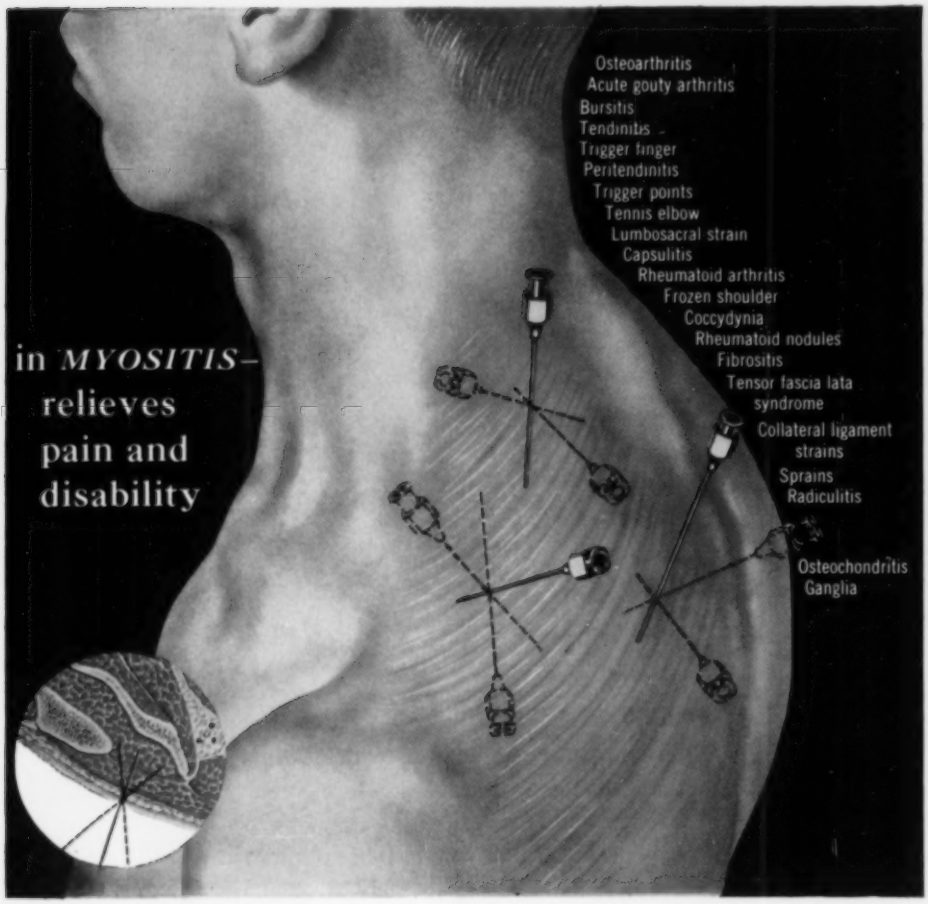
Custom Bootmakers Since 1884

BROCKTON, MASSACHUSETTS

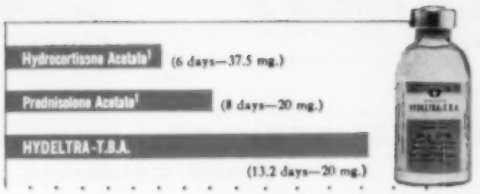
HYDELTRA® -T.B.A.

(Prednisolone *tertiary*-butylacetate, Merck)

for relief that lasts—longer



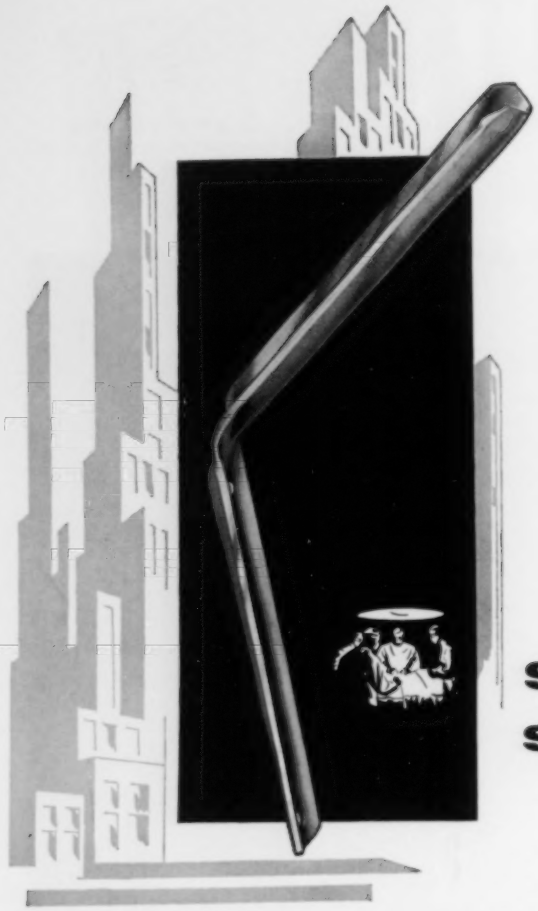
Anti-inflammatory effect lasts longer than that provided by any other steroid ester


Hydrocortisone Acetate[1]
(6 days—37.5 mg.)
Prednisolone Acetate[1]
(8 days—20 mg.)
HYDELTRA-T.B.A.
(13.2 days—20 mg.)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 DAYS

Dosage: the usual intra-articular, intra-bursal or soft tissue dose ranges from 20 to 30 mg. depending on location and extent of pathology.

Supplied: Suspension "HYDELTRA"-T.B.A.—20 mg./cc. of prednisolone *tertiary*-butylacetate, in 5-cc. vials.

MERCK SHARP & DOHME
DIVISION OF MERCK & CO., INC.
PHILADELPHIA 1, PA.



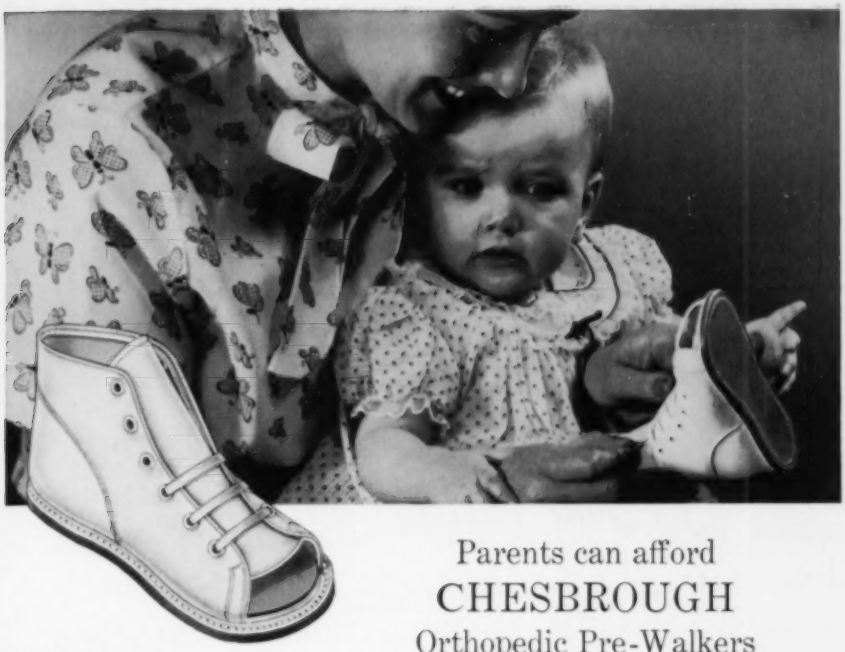
STRUCTURALLY SOUND

NEUFELD FEMORAL NAIL PLATES

have been engineered to provide maximum strength at the bend. Available in either Neutrilium (cobalt alloy) or type 316 stainless steel with screws of identical metals . . . The Neufeld nail is the choice of careful, discriminating orthopedic surgeons.

Ask your Surgical Supply Dealer or
write for additional technical information

MEDICAL RESEARCH SPECIALTIES
Loma Linda, California

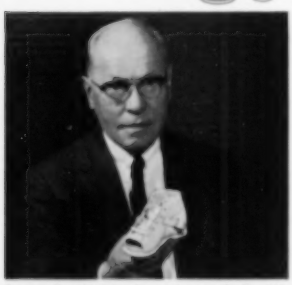


Parents can afford CHESBROUGH Orthopedic Pre-Walkers

No. 1400 OPEN TOE
Straight-line symmetrical last, firm heel, no back seam. Adaptable to Denis Browne Splints.

No. 1300 CLOSED TOE
Lace-to-toe design permits snug, gentle fit. Perfectly smooth inside.

No. 1700 CLUBFOOT, OPEN TOE
Special outflare last, sturdy instep strap to stabilize heel.



Louis C. Weld, President of G. W. Chesbrough Co. . . . "My own personal experience led to the development of the new Chesbrough Shoe."

Here are Orthopedic infants' shoes that meet rigid requirements of corrective footwear yet fit the family budget.

High-quality workmanship and fine leathers with orthopedically correct lasts are combined in Chesbrough Shoes to sell at a moderate price.

Any parent whose child requires orthopedic correction knows the expense is great, as frequent purchase of new shoes is required.

This problem was brought home to Chesbrough's president, Louis C. Weld, three years ago, when a child in his own family needed such a shoe. Recognizing the need for orthopedic shoes at an economical price, Chesbrough Company put their 60 years of shoemaking experience to work and Chesbrough Corrective Pre-Walker Shoes were born.

All shoes in unlined white elk, sizes 000 to 4, narrow and wide. Available in full pairs, split pairs or single shoes (no extra charge for half pairs).

MAIL COUPON FOR FREE DESK SAMPLES

G. W. CHESBROUGH CO.

807 Smith Street, Rochester 6, N. Y.

NAME .....

ADDRESS .....

CITY ..... STATE .....

YOUR ORTHOPEDIC SHOE DEALER:

.....

In answering advertisements, please mention *The Journal of Bone and Joint Surgery.*

"Gratifying" relief from

for your patients with
'low back syndrome' and
other musculoskeletal disorders

POTENT muscle relaxation
EFFECTIVE pain relief
SAFE for prolonged use

In answering advertisements, please mention *The Journal of Bone and Joint Surgery.*

stiffness and pain

"gratifying" *relief from stiffness and pain in 106-patient controlled study*

(as reported in J.A.M.A., April 30, 1960)

"Particularly gratifying was the drug's [SOMA'S] ability to relax muscular spasm, relieve pain, and restore normal movement . . . Its prompt action, ability to provide objective and subjective assistance, and freedom from undesirable effects recommend it for use as a muscle relaxant and analgesic drug of great benefit in the conservative management of the 'low back syndrome'."

Kestler, O.: Conservative Management of "Low Back Syndrome", J.A.M.A. 172: 2039 (April 30) 1960.

FASTER IMPROVEMENT—79% complete or marked improvement in 7 days (Kestler).

EASY TO USE—Usual adult dose is one 350 mg. tablet three times daily and at bedtime.

SUPPLIED: 350 mg., white tablets, bottles of 50.
For pediatric use, 250 mg., orange capsules, bottles of 50.

Literature and samples on request.

SOMA®

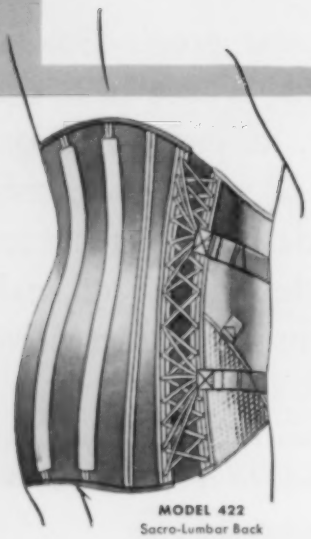
(CARISOPRODOL WALLACE)

WALLACE LABORATORIES, CRANBURY, NEW JERSEY

In answering advertisements, please mention *The Journal of Bone and Joint Surgery.*

Benefits of steel braces **. . . plus comfort**

Prescribe Freeman Scientific Corset-Type BACK BRACES



MODEL 422
Sacro-Lumbar Back Support For Men
MODEL 423 for Women

Therapeutic benefits associated with various types of steel braces may be achieved with fine Freeman corset-type supports. For 68 years, Freeman has consulted with orthopedic surgeons to provide this scientifically designed Back Support that permits easy adjustment to brace your patient in any degree to almost complete immobilization.

Your patients will appreciate the unsurpassed tailoring and excellent fit of Freeman back braces that provide the utmost comfort in sitting, standing and reclining positions. And they'll welcome the bonus luxury of Freeman's soft, comfortable interior finish that avoids irritation. Exterior is made of Pima Cotton and Dacron Fabric.

PRESCRIBE *Freeman* WITH CONFIDENCE

FREEMAN MANUFACTURING CO.
Dept. 709, Sturgis, Michigan

Please send details on new Freeman features and include free reference catalog.

Name_____

Address_____

City_____ Zone___ State_____

Freeman makes Full-Fashioned Elastic Hose and a complete selection of Maternity Garments in addition to . . .

- **ABDOMINAL SUPPORTS**
- **SACRO-ILIAC SUPPORTS**
- **POST OPERATIVE SUPPORTS**

self-broaching medullary nails by Orthopedic . . . available only in

SMo

AISI 316-317

"AISI 316 and 317 stainless steel has borne the test of time commendably in the field of surgical implants . . . The corrosion resistance of AISI 316 and 317 stainless steel is very satisfactory under most conditions."

METALS AND ENGINEERING IN BONE AND JOINT SURGERY
By Drs. Charles O. Bechtol, Albert B. Ferguson, Jr. and Patrick G. Laing. (Williams and Wilkins—1959)

Available through your surgical supply dealer.

CROSS SECTION

SCHNEIDER

Diameters: 8mm, 9mm, 10mm, 11mm, 12mm, 13mm

CROSS SECTION

HANSEN-STREET

Diameters: 9mm x 7mm, 11mm x 8mm, 13mm x 11mm

OEC

Your sign of Quality

ORTHOPEDIC EQUIPMENT CO.

Bourbon, Indiana

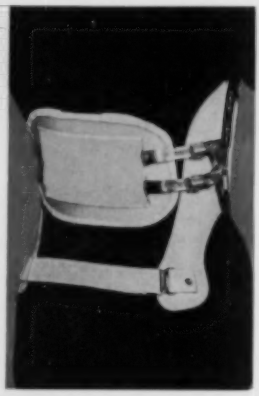
EUROPEAN ASSOCIATES: ZIMMER ORTHOPAEDIC LTD., Bridgend, Glam. Great Britain. ORTOPEDIA G.m.b.H. KIEL Kiel, Germany.

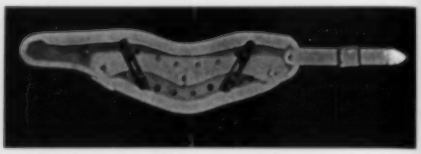
THE JEWETT HYPEREXTENSION BACK BRACE

This brace has proven its worth as a satisfactory hyperextension immobilization device in cases of uncomplicated compression fractures of the lower thoracic and entire lumbar spine. It maintains desired hyperextension as well or better than the best applied hyperextension plaster of paris cast. The brace weighs only a fraction of the weight of a cast, permits desired body hygiene and usually can be worn beneath ordinary garments with little or no alteration. Another advantage of the brace is its adjustability without loss of its hyperextension qualities.

SPINAL FUSION MODEL

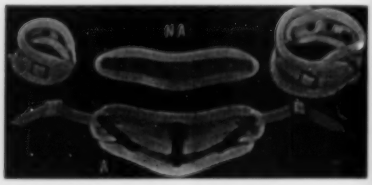
The spinal fusion model has additional advantages which make it an admirable post-lower fusion brace where minimal motion in the fused area is desired.





MYO-CERVICAL COLLAR

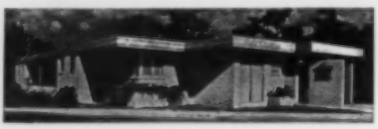
For cases such as whip-lash injuries, wry neck, torticollis, etc.; adjustable as to height and degree of extension. Lower perimeter adjusts automatically to contour of sternum and clavicle. Light, cool, comfortable and washable; provides positive support. Available in small, small-special, medium and large sizes.



EXTENSION-FLEXION COLLAR—The Universal Cervical Collar

Indicated in those conditions requiring positive support and immobilization such as whip-lash injuries, wry neck and torticollis; also as an adjunct to braces or plaster casts in certain other post-traumatic and post-operative cervical lesions. This reversible collar may be used to maintain **extension, flexion** or **stabilization;** is semi-rigid, ventilated, completely cushioned and adjustable to height, circumference and degree of extension or flexion. All parts are interchangeable and washable. Available in small, medium and large sizes with interchanging of parts to make possible eighteen various sizes by use of double buckle straps.

Literature, reprints and measuring charts upon request or better still, the name and address of our nearest bracemaker-distributor.



FLORIDA BRACE CORPORATION

Post Office Box 1366 • Winter Park 3, Florida
Phone Midway 4-2650

In answering advertisements, please mention *The Journal of Bone and Joint Surgery.*

A Work of Art

A Work of Art
by Jacopo Sansovino (Italian 1486-1570). One of the great Renaissance sculptors and architects. His masterpiece is the Library of St. Marks (1536) in Venice.

With **STUCCA** Plaster of Paris bandage you create a work of art . . . a perfect cast . . . with speed, strength, fidelity – assuring firm support and immobilization for every type of fracture, every time.

STUCCA's creamy, consistently smooth plaster is easily applied, conforms precisely to body contours and, when dry, can take heavy abuse – so important with active children! And it's lightweight, too.

STUCCA's great final strength means you can construct lighter casts thus providing greater patient comfort and reduced X-ray exposure time.

Extra-fast setting time, 2-4 minutes. Or you can control the setting speed yourself.

For complete data and FREE sample sufficient for your own testing purposes, write today.

ACME STUCCA

ACME COTTON PRODUCTS CO., INC.
245 FIFTH AVENUE, NEW YORK 16, NEW YORK

SABEL'S

BASIC SHOES

TRADE MARK REG. U. S. PAT. OF

FROM BASIC TO HIGHLY SPECIALIZED FOOTWEAR

Sabel features a complete line of men's and boy's shoes built on scientifically designed lasts, drafted to fit the foot shape without restriction . . . with long counters, tempered steel shanks and full Thomas heels.

Sabel also features a lace to toe surgical boot for men and boys . . . for post-operative cases where a full heel to toe adjustment is required . . . for brace or special corrective work.

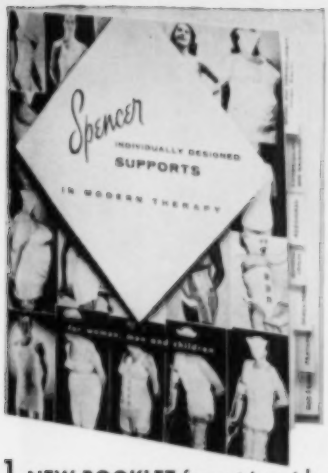
And Sabel dealers carry the shoes in-stock. No long waits . . . no delays. Sabel dealers are trained specialists in the fitting of prescribed corrections . . . for men, women, infants and children.

Manufactured exclusively by
C. H. ALDEN SHOE CO., Brockton, Mass.

For further information, write
I. SABEL, Inc., 1207 Chestnut St., Philadelphia, Penn.

OVER
1300
AGENCIES
Coast to Coast

THE MOST COMPLETE BASIC SHOE PROGRAM IN THE ORTHOPEDIC FIELD

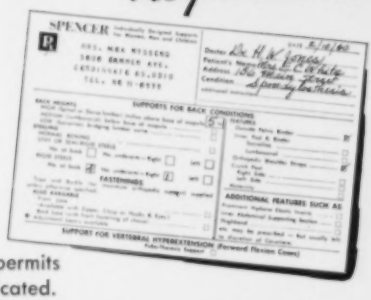


SIMPLE AS 1-2-3 TO PRESCRIBE

Spencer®

INDIVIDUALLY DESIGNED SUPPORTS
to meet patient's

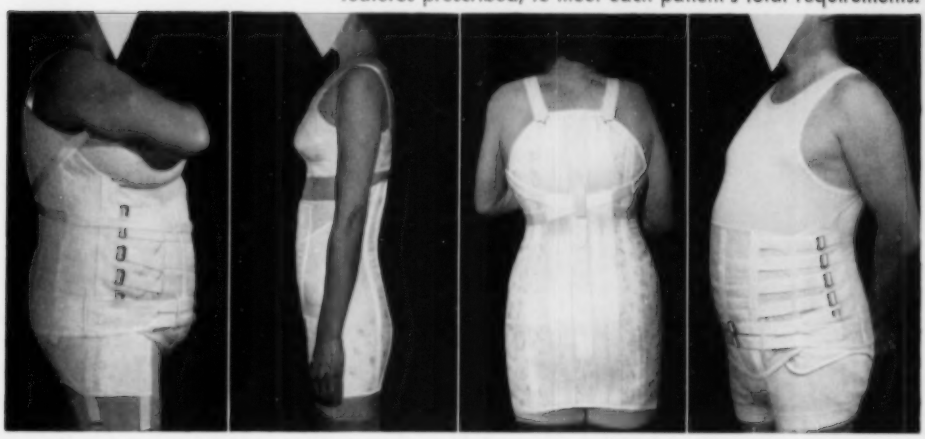
Individual and Total Requirements



1. NEW BOOKLET format is guide to Spencer's comprehensive prescription service, illustrating specific features available for use at professional discretion.

2. NEW PRESCRIPTION FORM permits physician to check features indicated.

3. SPENCER SUPPORTS are individually designed, incorporating features prescribed, to meet each patient's total requirements.



Spencer's Individual Designing Service is available to you through Corsetieres specially trained to help you help your patients.

MAIL COUPON NOW

SPENCER®
individually designed supports for women, men and children

SPENCER, INCORPORATED
19 Ellsworth Ave., New Haven 7, Conn.
Canada: Spencer, Ltd., Rock Island, Quebec
England: Spencer, Ltd., Banbury, Oxon

☐ Send me the new booklet guide to Spencer prescription service.
☐ I would like an office demonstration of Spencer.

Name _____
Address _____
_____
9-60

to make the most of your talents and techniques . . .

Love-Kerrison Rongeur Forceps

The performance of his cutting instruments is a major concern of the surgeon . . . especially in laminectomy. The Love-Kerrison Rongeur Forceps assures smooth, powerful, dependable, clean-cutting action. Six-inch shanks give ample depth. Up-cutting, with 5 mm. or 3 mm. bite. Stainless steel. Order as No. NL-6000 (5 mm.) or NL-6001 (3 mm.), each $52.50.

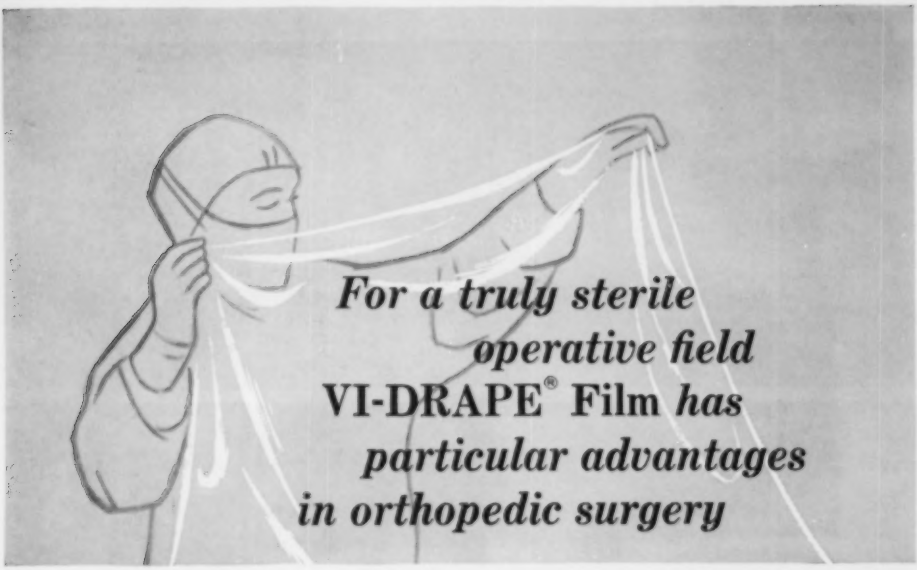
VMUELLER & CO.

Fine Surgical Instruments and Hospital Equipment Since 1895

330 S. Honore Street, Chicago 12, Illinois

Dallas • Houston • Los Angeles • Rochester, Minn.

In answering advertisements, please mention *The Journal of Bone and Joint Surgery.*



For a truly sterile operative field VI-DRAPE® Film *has particular advantages in orthopedic surgery*

Vi-Drape Film completely isolates the patient's skin from the wound and maintains the sterility of the operative site. It is a soft, pliant transparent plastic sheet which is adhered intimately and firmly to the surgically prepared skin with Vi-Hesive® Adherant. Incision is made right through the plastic bacterial barrier. Protection is complete to the incisional edge, and remains so even during lengthy procedures. Encumbering skin towels and clips are avoided.

Extremities can be sealed off by loose wrapping of Vi-Drape Film to avoid contamination of other areas. Film should be adhered tightly at operative site. Photo—Ralph Adams, M. D., Boston, Mass., and Wolfeboro, N.H.

Visibility of landmarks and maintenance of asepsis in previously hard-to-drape areas are advantageous—as in the above knee operation contemplating re-entry. Vi-Drape Film conforms to contour. Photo—Robert M. Zollinger, M.D., William G. Pace, M.D. and Marjorie J. Reed, R.N., Columbus, Ohio

Smooth molding and close adherence of the plastic film to the difficult contour of the hip, provides an aseptic operative area previously considered almost impossible to achieve.
Photo — Chas. G. Lovingood, M. D., Frank L. Shively, Jr., M. D. and Albert M. Storrs, M. D., Dayton, Ohio

Would you like to see a full-color sound motion picture further illustrating the application of Vi-Drape Film in varied surgical procedures? The film, "A New Transparent Plastic Surgical Drape," produced by Robert M. Zollinger, M.D., William G. Pace, M.D. and Marjorie J. Reed, R.N., at Ohio State University Department of Surgery, is available for showing to all members of the surgical team.

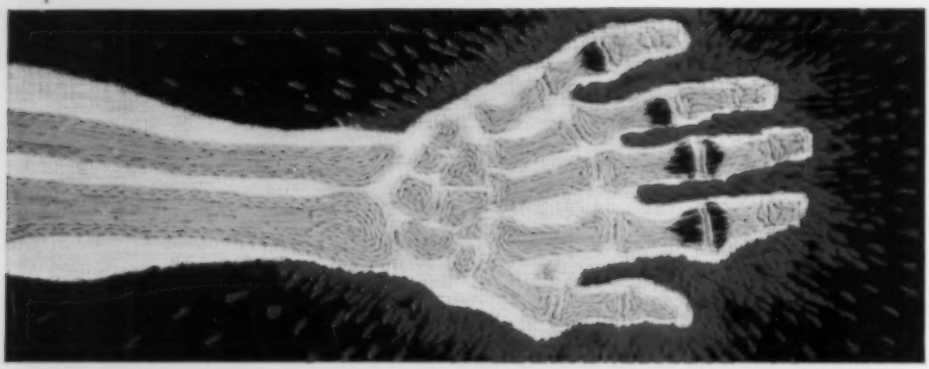
Please send requests to:
AEROPLAST CORPORATION
Station A-Box 1, Dayton 3, Ohio

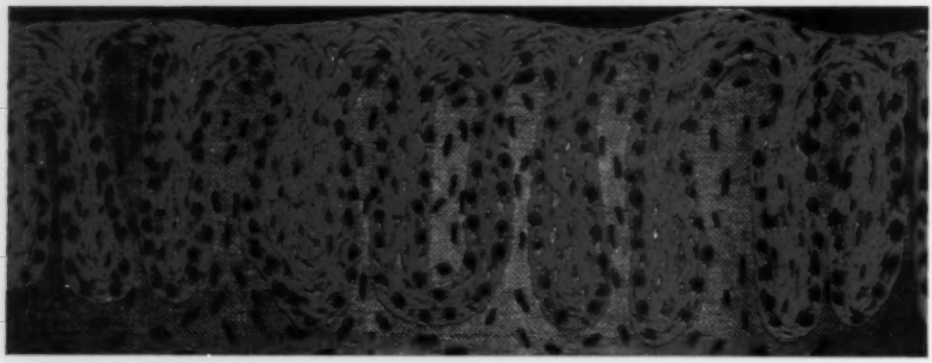
Patents Pending—Vi-Drape® Film is sterilizable, Vi-Hesive® Adherant is sterile.

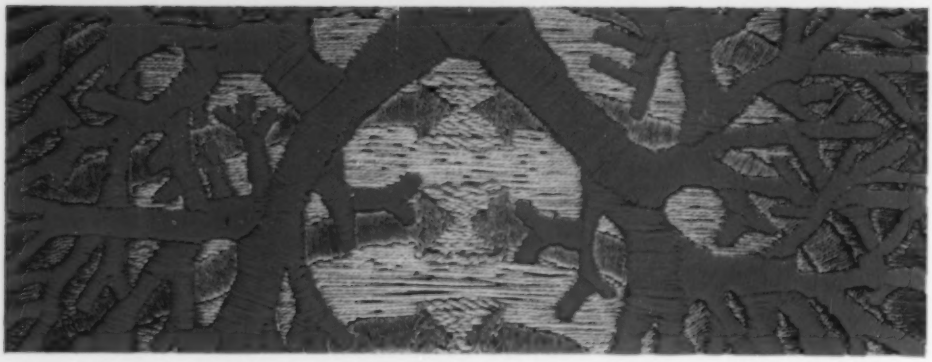
All photos shown are of actual procedures.

In answering advertisements, please mention *The Journal of Bone and Joint Surgery.*

a promise fulfilled







All corticosteroids provide symptomatic control in rheumatoid arthritis, inflammatory dermatoses, and bronchial asthma. They *differ* in the frequency and severity of side effects. Introduced in 1958, ARISTOCORT Triamcinolone bore the promise of high efficacy and relative safety. Physicians today recognize that the promise has been fulfilled . . . as evidenced by the high rate of refilled ARISTOCORT prescriptions.

Aristocort® Triamcinolone LEDERLE

Lederle LEDERLE LABORATORIES, A Division of AMERICAN CYANAMID COMPANY, Pearl River, N.Y.

In answering advertisements, please mention *The Journal of Bone and Joint Surgery.*

Put new spring in your step

* TM Ripple Sole Corp.

Spring-action

*RIPPLE® Sole SHOES

The SURGEON
Supportive counter.
$21.95** ppd.

The NURSE
Supportive counter
$20.95** ppd

Here's good news for those who stand or walk long hours on their feet . . . a new, super-flexible "footing", RIPPLE® Sole, called in an article in Reader's Digest: "the most important improvement in footwear since Julius Caesar put heels on the boots of his legionnaires".

A series of flexible corrugations that depress when stepped on, then spring back to put pep in your step, RIPPLE® Sole has been tested and proven to help absorb shock, cause of most foot fatigue. Many doctors and nurses wear them, "live" in them. Try a pair yourself. Take a few steps. You'll never wear a more comfortable shoe. Satisfaction guaranteed. ORDER TODAY (give size, width) or write for FREE folder (smart styles for the whole family). **Mich. orders add 3% tax. (Men's, over size 12, add $1.50; women's over 10, add $1.) Conductive plug and heel seat, $3 extra.

Let shock-absorbing RIPPLE® Sole shoes ease every step for your patients as well. Remember — this resilient cushion not only reduces the resultant jar when the heel strikes a hard surface, but protects against dampness, cold and wet — and — no rubbers needed!

THE HACK SHOE COMPANY, 5041 Mutual Building, Detroit 26, Michigan

Please send me ☐ Technical information on RIPPLE® Sole
☐ Free style folder ☐ NURSE ☐ SURGEON
Size....Width....

NAME_____

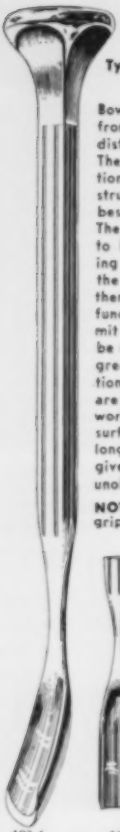
ADDRESS_____

CITY_____ ZONE_____ STATE_____

ACCLAIMED BY SURGEONS AS THE LIFETIME INSTRUMENTS

Because of Their Quality and Durability

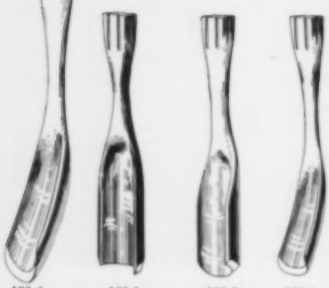
GOUGES



Type 440C Stainless Steel—Swedish Hand Forged

Bowen Gouges, Hand Forged from 44C stainless steel, are of distinctive design and style. The forging method of fabrication produces a fine grain instrument in curves and shapes best desired by the surgeon. The edges are hollow ground to keen razor sharpness resulting in a minimum of effort on the part of the surgeon to make them perform their intended function. The four styles permit a wide range of work to be done. They will be found of great value in bone reconstruction work. The Curved Gouges are particularly adaptable to work in and around contoured surfaces. The fine balance and long square grooved handles give a feeling of sure grip and unobstructed vision.

NOTE: Available with finger grips if desired.



103-4 103-1 103-2 103-3

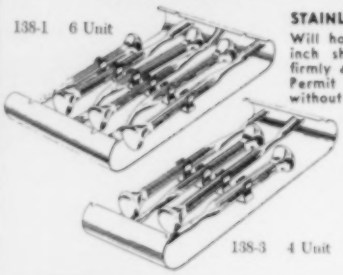
Consult Your Dealer or Write to:

BOWEN & COMPANY, Inc.

P. O. BOX 5818

BETHESDA, MARYLAND

INSTRUMENT TRAYS



138-1 6 Unit

138-3 4 Unit

STAINLESS STEEL

Will hold any instrument with a ⅜-inch shank. Will hold instruments firmly and prevent possible damage. Permit sterilization of instruments without individual handling.

FEATURES:

"Four and six unit trays will nest, one on top of the other." "Trays may be placed on end." "Requires less storage space." "Instruments cannot fall out if tray is turned over."

HATT SPOON—SPINAL GOUGE

103-5

In spinal and arthroplasty surgery, the use of the Spinal Gouge along with our Arthroplasty and Goose Neck Gouges give the surgeon a combination of instruments best suited in this often difficult and intricate work.

FEATURES: "Keen cutting edge." "Hardened and tempered to rigid specifications for maximum quality." "Thumb rest handle designed to insure grip and prevent slipping." "Long handles for unobstructed vision."

No. 103-5 Hatt Spoon—Spinal Gouge.

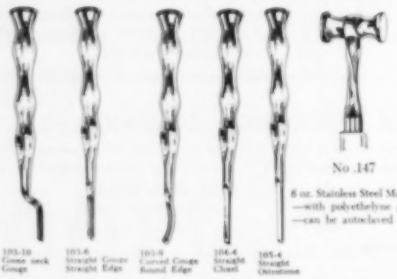
NOTE: Available with finger grips if desired.

CHISELS—GOUGES—OSTEOTOMES

For Surgery of the Hand

Type 440C Stainless Steel—Swedish Hand Forged

Contoured handles to comfortably fit the fingers of the hand so that holding the instruments will be easy and with a secure feeling. The average overall length of the instruments is approximately 6½ inches. The chisels and osteotomes are available in a goose neck blade such as illustrated below by the goose neck gouge.



No .147

6 oz. Stainless Steel Mallet —with polyethylene grip —can be autoclaved

FOR THAT EXTRA MEASURE OF RELIEF
IN SEVERELY PAINFUL RHEUMATIC AND TRAUMATIC DISORDERS

NEW

PARAFON

WITH

CODEINE

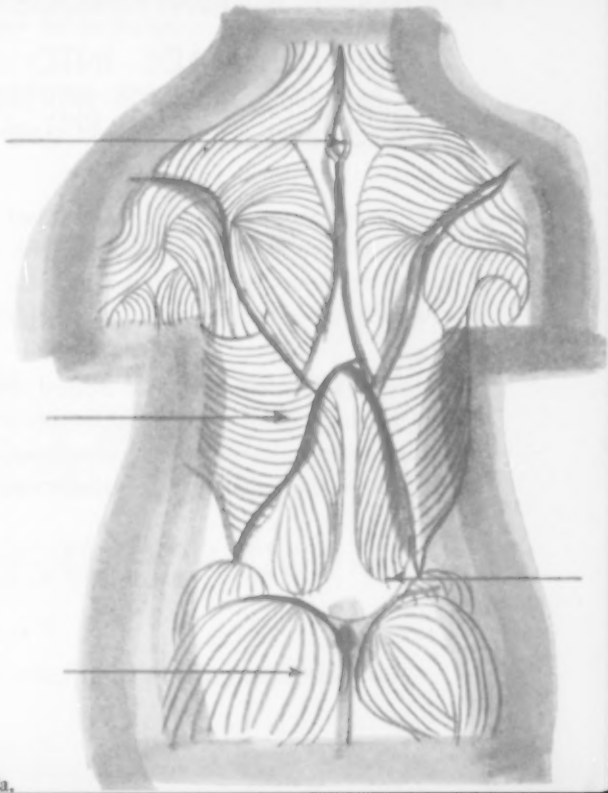
The addition of the unrivaled analgesic potency of codeine phosphate to PARAFON provides the muscle relaxant-analgesic effect necessary in severely painful musculoskeletal disorders. In these conditions, PARAFON with Codeine◇ assures long-lasting relief of pain, stiffness and disability on low, practical dosage. Side effects are rare and seldom severe enough to warrant discontinuation of therapy.

dosage: One to two tablets 3 or 4 times a day.

supplied: White, compressed tablets, imprinted McNEIL, bottles of 24. Each tablet contains: PARAFLEX® Chlorzoxazone* 125 mg., TYLENOL® Acetaminophen 300 mg., and codeine phosphate 15 mg.

*U. S. Patent Pending

◇Narcotic for which oral Rx is permitted 307A59



McNEIL

McNeil Laboratories, Inc • Philadelphia 32, Pa.

Makes Molehills out of Mountains!

PAT. NO. 2,579,968

MANY MOUNTAINOUS FRACTURE PROBLEMS CAN BE MADE INTO SIMPLE ONES WHEN RUSH PINS ARE PHYSIOLOGICALLY APPLIED.

Proper application of the RUSH PIN is not always easy. It takes a while to learn. It is quite different in principle and technic from other forms of medullary fixation. It is not designed to impact the marrow cavity, but to accurately transfix the fractured bone by points of pressure, precisely applied.

The ingenious surgeon, who has added this to his knowledge and skills, has simplified his tasks and contributed pleasure to his patients. He minimizes surgery and speeds convalescence with unbelievably early motion, even in fractures near joints. Removable splints are sometimes used, but casts or traction, rarely.

**"The Rush Medullary Pin" and "Berivon" are registered trademarks of The Berivon Company*

Because:

Every severe fracture has its characteristic deformity. You might call it muscle pull or intrinsic dynamic forces, but it is a deforming force.

For good fixation this force must be overcome. The muscle pull of the extremity must be utilized to advantage to provide contact compression. This is why the RUSH PIN came into being.

It was designed to exert a dynamic force of its own to resist this deforming force. It was designed to be introduced from the side of the bone, rarely from the end.

The **point** must drive through cancellous bone, deflect from the cortex, drive and guide easily, yet be effective in locking the distal fragment against rotation. That is why the RUSH PIN has the SLED RUNNER POINT.

The RUSH PIN must not impact the marrow cavity, but must lock the bone by points of pressure. That is why it must have exactly the right resilience. That is why it is made only of **Type 316 stainless steel of precise temper,** hand fashioned, cold worked and electropolished.

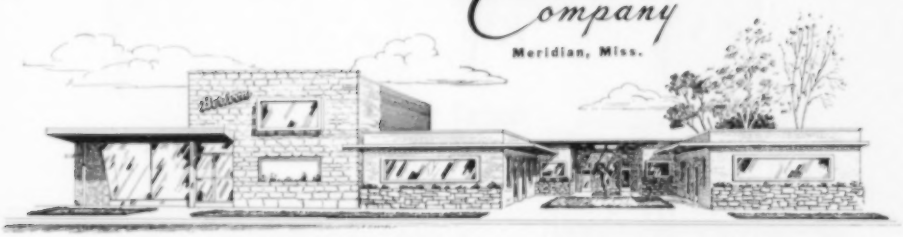
It required 15 years clinical research to perfect the design of the RUSH PIN and two years to perfect the proper temper for its metal.

THAT IS WHY EVERY GENUINE RUSH PIN THAT HAS EVER BEEN MADE WAS MADE BY BERIVON

Reprints Available

THE BERIVON Company

Meridian, Miss.



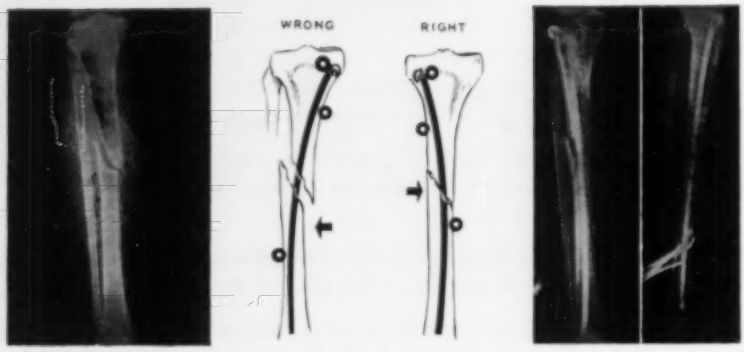
Exclusive Manufacturers of Rush Medullary Pins and Instruments
Publishers of "Atlas of Rush Pin Technics" by Leslie V. Rush, M.D.

Lock the Bone with Dynamics

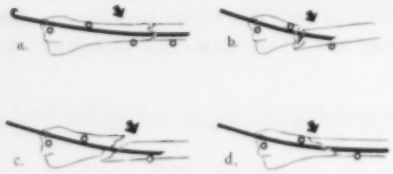
Oblique Fractures—Short Fragments*

The RUSH® MEDULLARY PIN

PAT. NO. 2,579,988



Direction of pin insertion determines compression or distraction.



V (victory) = Good Compression

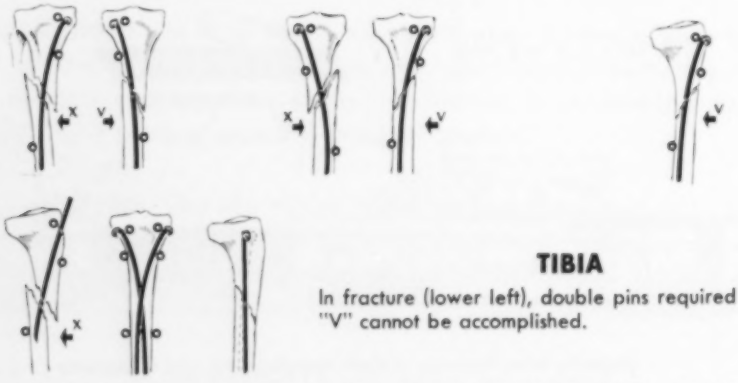
X (no good) = Distraction

RADIUS

Length of fragment and direction of fracture line determine angle of pin insertion.

RULE

Axis of pin should be same direction as axis of fracture line, intersecting to make a "V" instead of an "X".

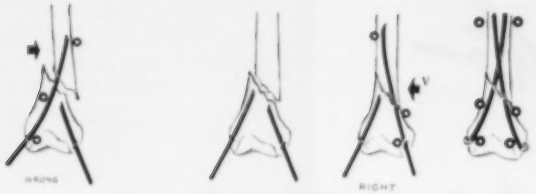


TIBIA

In fracture (lower left), double pins required because "V" cannot be accomplished.

* Rush, Leslie V.; Fracture Problems, Mississippi Doctor, Vol. 36, No. 10, March 1959.

In answering advertisements, please mention *The Journal of Bone and Joint Surgery.*



LOWER FEMUR

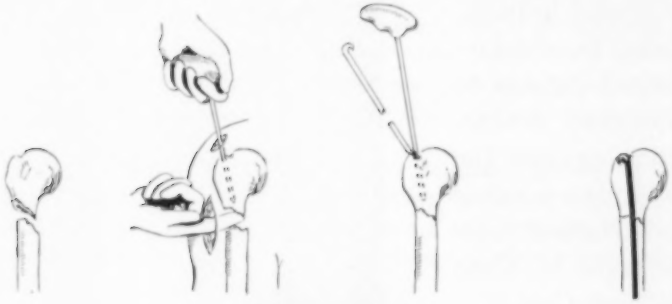
Double pins required. Introduce most effective pin first.

UPPER FEMUR

Dependent upon direction of fracture line, special type pin might be indicated.

HUMERUS, BELOW DELTOID

Requires precise handling for good healing. For fracture at right use large curved pin for compression.



UPPER THIRD

To avoid angulation, insert pin axially in short fragment.

WRITE FOR INFORMATION
Exclusive Manufacturers of
RUSH MEDULLARY PINS AND INSTRUMENTS
Publishers of
"ATLAS OF RUSH PIN TECHNICS"
by LESLIE V. RUSH, M. D.

THE BERIVON Company
MERIDIAN, MISS.

In answering advertisements, please mention *The Journal of Bone and Joint Surgery.*

Richards

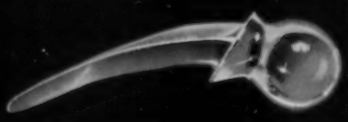
FEMORAL PROSTHESES

(SMo STAINLESS)

for every requirement

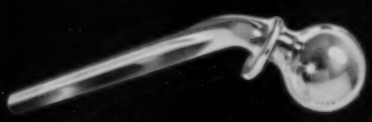
Richards Femoral Prostheses are solid forged, precision machined of SMo stainless, electropolished for optimum tissue tolerance. Offer maximum ductility, maximum strength, mirror finish and hollow concentric head for reduced weight. These popular forms available with specially designed rasps and broach to facilitate insertion. Teflon faced drivehead assures against damage to polished, precision head, producing smooth motion against the acetabulum, precludes possible contamination to surface of prosthesis head. Packaged in Kane Sterifabric Sterilizing Case.

Write For Full Information

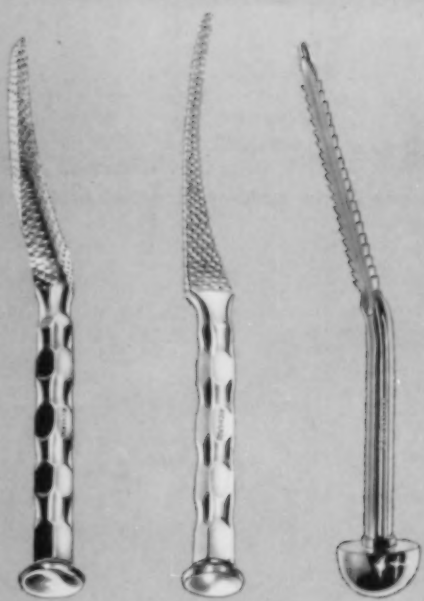


F. R. Thompson Type Hip Prosthesis — Popular choice of surgeons because of its ease of insertion and good results.

Moore Type Hip Prosthesis — Holes in stem allow bone growth through the prosthesis (sometimes filled with bone crumbs before insertion).



Eicher Type Hip Prosthesis — Tri-finned shaft, available in two diameters. Shaft length 5½".



Rasp for F. R. Thompson type prosthesis.

Rasp for Moore type prosthesis.

Broach for Eicher type prosthesis.

Teflon Faced Drivehead — Anodized aluminum body. Totally inert driving face of Teflon. Concave face fits all heads. May be autoclaved.

Richards

MANUFACTURING COMPANY

756 Madison Avenue, Memphis 3, Tenn.

VOLUME 42-A, NO. 6 SEPTEMBER 1960

The Journal of
Bone and Joint Surgery

American Volume

Electromyographic Study of Transplanted Muscles about the Knee in Poliomyelitic Patients*†

BY DAVID H. SUTHERLAND, M.D., FREDERICK C. BOST, M.D.,‡
AND EDWIN R. SCHOTTSTAEDT, M.D., SAN FRANCISCO, CALIFORNIA

From the Shriners' Hospital for Crippled Children, San Francisco

Many questions have been raised regarding the function of muscle transplants about the knee performed to compensate for paralysis of the quadriceps femoris. Clinical follow-up studies of relatively large numbers of transplants have been reported [1,4,8]. These studies were based largely on personal interview and manual muscle testing. Kuhlman and Bell noted that the poorest functional results were obtained in transplantations of the tensor fasciae latae and sartorius muscles to the patella.

Although manual testing of a transplant gives considerable information regarding its function under a single set of circumstances, it is important that we learn more about the behavior of transplants under conditions of normal level walking and under a variety of other conditions. The basic problem in all the clinical studies has been the difficulty of accurately relating muscle contraction to gait.

Our present concepts of phasic activity of muscles originated in the early work of Scherb. He is given credit for first defining the patterns and sequence of the muscle action in the lower extremities during gait. Initially, muscle action was determined simply by palpation as the patient walked on a treadmill. Later, electromyography was introduced.

The work of Inman, Saunders, Eberhardt and co-workers [5] clarified the concept that an orderly sequence of muscle contractions occurs in the lower extremities during gait. Electromyograms and gait movies, made simultaneously, were matched to define the exact timing and intensity of muscle contractions as related to gait. The action potentials of twenty-eight specific muscles of the lower

* Read at the Annual Meeting of The American Orthopaedic Association, Lake Placid, New York, June 17, 1959.

† This study was carried out at the Shriners' Hospital for Crippled Children, San Francisco, and was entirely supported by funds provided by the Shriners' Organization through a special research grant.

‡ Deceased.

extremity in six subjects were recorded by use of dual internal electrodes. The subjects walked on a level surface at both a normal and a rapid pace and then up and down stairs and up and down a ramp. Composite linear graphs of the phasic activity of each muscle under the conditions described were prepared. Although there were great variations in the phasic activity of the muscles during the various activities tested, there appeared to be little difference in the duration and timing of the phasic activity of the muscles during normal level walking and fast level walking except in the long head of the biceps femoris, the gracilis, the rectus femoris, and the vastus intermedius. Each of these muscles showed an increase in stance-phase activity during fast level walking as compared with normal level walking. This pioneer work provides a solid foundation for an understanding of the phasic activity of normal muscles in the lower extremity in normal level walking and in the other activities listed. Without a proper conception of the normal phasic activity, electromyographic studies of transplanted muscles in the lower extremity would have little meaning.

Weiss and Brown reported electromyographic studies, using surface electrodes, of twenty cases of biceps femoris transplantation to the patella; we believe that internal electrodes are essential for accurate identification. Recordings were made of the transposed muscle and two other muscles representing the opposing phase of joint motion. Exact portrayal of the phasic activity of these muscles as related to gait was not given. The authors concluded from their study that after transp antation the biceps femoris continues to function in its former phase at first, but then it begins to function in both phases and, finally, it functions only in the extensor phase. They report that temporary relapses into the old flexor phase were noted even many years after operation. These relapses were thought to be favored by fatigue, lack of concentration, and automatic movements.

Close and Todd reported electromyographic studies of a large number of transplanted muscles as well as of some normal muscles in the lower extremity. Dual wire internal electrodes were utilized, and the position of the electrodes was carefully checked by stimulation. Individual recordings were made of 125 muscles after tendon transfer had been done. The oscilloscope tracing was photographed with a continuously recording oscilloscope camera. The vertical output of the cathode-ray oscilloscope was connected to the amplifier of the sound motion-picture camera. Seventeen patients with transfers of the biceps femoris to the patella were studied, and it was concluded that swing-phase activity of this muscle is usually retained. Tracings were shown of two patients in whom the swing-phase activity appeared to be retained and of one patient with excellent conversion of the biceps femoris to the stance phase. Another patient showed conversion of the semitendinosus to the stance phase. From their studies of the transplants in the lower extremities, Close and Todd concluded that the best results were obtained when the transplant did not involve change of phase of the muscle being transplanted, although there were a number of exceptions to this general principle.

Our study was initiated to seek further detailed information regarding the phasic activity of transplanted muscles about the knee in patients with paralysis due to poliomyelitis. If a muscle has been transplanted to compensate for paralysis of the quadriceps femoris, it is reasonable to hope that it will function during the same phase of gait as the quadriceps. We have compared the phasic activity of the transplanted muscles to that of the normal quadriceps and have also determined the phasic activity of some of the other muscles of the hip and thigh that may have a bearing on stabilization of the knee. All of the electromyographic studies to date, including our own, give insufficient data regarding the over-all patterns of phasic activity of the associated muscles.

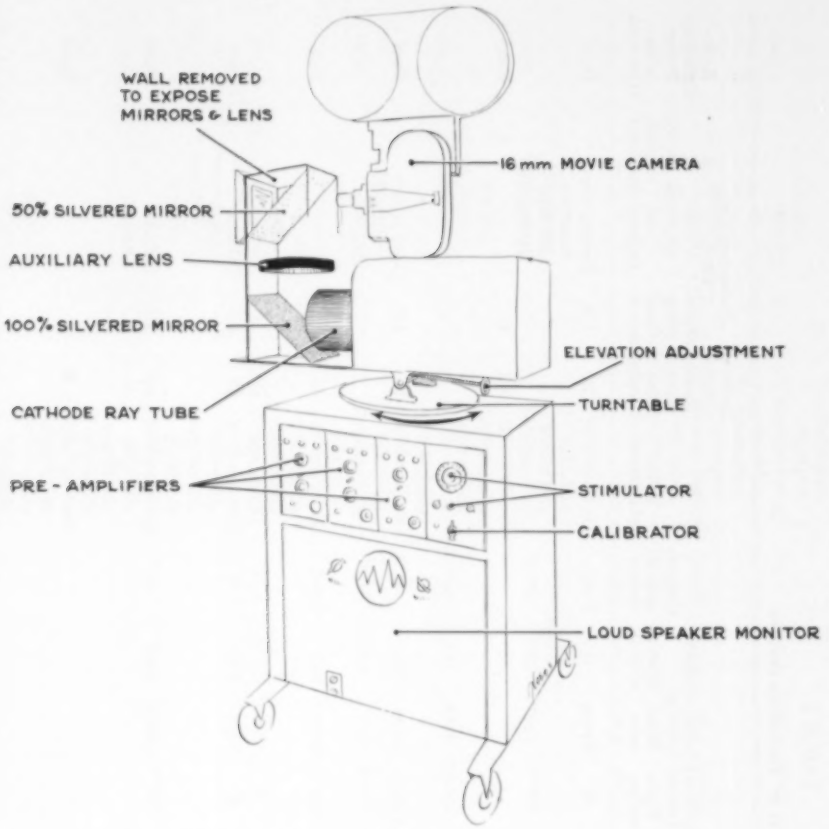


FIG. 1

Recording equipment designed and constructed by the Research and Development Laboratory, University of California Medical Center, San Francisco. The two mirrors and lens reflect and focus the oscilloscopic image, superimposing muscle potentials and subject. The upper mirror placed at a 45-degree angle in front of the camera lens is partially silvered to permit the camera to "see through the mirror to photograph the patient".

SELECTION OF PATIENT

Twenty-one patients with thirty-nine muscle transplantations about the knee were studied in this group. All the patients, prior to surgery, exhibited symptoms and signs of quadriceps insufficiency as a result of poliomyelitis. The surgery in each case was carried out by one of us (F. C. B.) and his associates. The patients' ages varied from ten to fifteen years at the time of this study. Intervals between transplantation and this follow-up study varied between three and one-half months and seventy-two months. Pertinent data regarding each patient are given in Table I. Six control patients, whose ages ranged from ten to thirty-five years, were also studied. They were normal in every respect.

RECORDING EQUIPMENT

Our present equipment was designed and constructed in the Research and Development Laboratory of the University of California Medical Center, San Francisco. Robert Vreeland and Joseph Dorsa were chiefly responsible for its successful completion. The equipment consists of a three-channel electromyograph with an oscilloscope and a sixteen-millimeter Bolex movie camera mounted on a

TABLE I

RESULTS IN TRANSPLANTATIONS

Case No.	Year of Birth	Age at Onset of Poliomyelitis (*Years*)	Knee-Extension Power before Operation	Muscles and Ratings in Involved Limb before Surgery: Tensor	Sartorius	Iliopsoas	Quadriceps	Medial Hamstring	Lateral Hamstring	Gluteus Maximus	Gluteus Medius	Gastrocnemius-Soleus	Transplantation	Interval Since Transplantation (*Months*)	Involvement in Limb: Shortening (*Centimeters*)	Contractures and Deformities	Brace Eliminated	Knee-Extension Power after Operation
1	1948	1½	0	Fair	Fair	Fair	0	Poor	0	Trace	0	Poor	Distal ends of sartorius and tensor to patella	72	1.5	Flexion contracture, left hip, 15 degrees		Poor
(2nd operation)			Poor										Proximal end of sartorius and patella to trochanter	2	0		x	Poor
2	1946	5	Poor	Normal	Good	Good	Poor	Good	Good	Good	Fair	0	Distal ends of sartorius and tensor to patella	15	1.0	Genu recurvatum, 15 degrees	x	Poor
3	1949	5	Trace	Fair	Fair	Fair	Trace	Fair	Fair	Poor	Fair	Good	Distal ends of sartorius and tensor to patella	45			x	Fair
4	1948	2	Poor	Fair	Fair	Fair	Poor	Poor	0	Poor	Fair	0	Distal ends of sartorius and tensor to patella	48	4.5	Talipes valgus		Poor
5	1948	1	0	Good	Good	Fair	0	Fair	0	Good	Poor	0	Distal ends of sartorius and tensor to patella	45	2.8	Talipes varus	x	Poor
(2nd operation)			Fair										Proximal end of sartorius to trochanter	2				Fair

6	1949	2	0	Fair	Fair	Poor	0	0	0	Good	Poor	Poor	Distal ends of sartorius and tensor to patella	24	1.8	Genu recurvatum, 10 degrees		Poor
(2nd operation)			Poor										Proximal end of sartorius to trochanter	2			x	Poor
7	1951	5	0	Faint	Faint	Fair	0	Trace	Trace	Poor	Trace	0	Distal ends of sartorius and tensor to patella	6	1.1	Talipes equinus, 10 degrees; hip flexion, 20 degrees		Poor
8	1944	1½	0	Fair	Fair	Poor	0	0	0	Fair	Poor	0	Distal ends of sartorius and tensor to patella	36	1.4	Genu recurvatum; pantalar arthrodesis, foot	x	Poor
9	1950	1	Poor	Fair	Fair	Fair	Poor	Good	Good	Fair	Fair	Good	Distal ends of sartorius and tensor to patella	24	3.7	Talipes equinus		Poor
10	1949	2	0	Fair	Fair	Fair	0	Good	Good	Fair	Good	Normal	Distal ends of sartorius and tensor to patella	48	2.5	Genu recurvatum, 15 degrees		Poor
11	1947	3½	0	Good	Poor	Trace	0	Good	Good	Good	Fair plus	Good	Biceps femoris and semitendinosus to patella	45	3.0	Knee flexion, 5 degrees		Good
12	1949	10/12	0	Fair	Fair	Fair	0	Good	Good	Fair	Fair	Good	Biceps femoris and semitendinosus to patella	18				Fair
13	1945	3	0	Fair	Poor	Fair	0	Good	Good	Fair	Fair	Good	Biceps femoris and semitendinosus to patella	72	3.17	Talipes valgus		Fair
14	1949	9/12	0	Poor	Poor	Trace	0	Fair	Good	Good	Poor	0	Biceps femoris and semitendinosus to patella	4	4.0	Talipes calcaneovarus		Poor

TABLE I *(Continued)*

Case No.	Year of Birth	Age at Onset of Poliomyelitis (*Years*)	Knee-Extension Power before Operation	Muscles and Ratings in Involved Limb before Surgery								Transplantation	Interval Since Transplantation (*Months*)	Involvement in Limb			Knee-Extension Power after Operation
				Tensor	Sartorius	Iliopsoas	Quadriceps	Medial Hamstring	Lateral Hamstring	Gluteus Maximus	Gluteus Medius	Gastrocnemius-Soleus			Shortening (*Centimeters*)	Contractures and Deformities	Brace Eliminated	
15	1947	6	Trace	Good	Good	Good	Trace	Good	Good	Good	Fair	Good	Biceps femoris and semitendinosus to patella	18	0	Knee flexion, 5 degrees		Good
16	1944	4	0	0	0	0	0	0	Good	Poor	Trace	0	Biceps medially to patella	36	0.7	Knee flexion, 10 degrees; pantalar arthrodesis, foot		Fair
17	1945	1	0	0	0	Fair	0	Good	Good	Poor	Poor	Good	Biceps femoris and semitendinosus to patella	3½	2.5	Knee flexion, 10 degrees; talipes equinus, 10 degrees		Fair
18	1948	1½	0	Good	Good	Poor	0	Good	Good	Good	Good	Good	Biceps femoris to patella	72	1.1			Fair
(2nd operation)													Distal end of sartorius to patella	48				Good
19	1945	2	0	Normal	Good	Fair	Trace	Fair	Good	Good	Fair plus	Normal	Biceps femoris medially to patella	36	2.2	Talipes equinus, 10 degrees; knee flexion, 10 degrees		Fair
20	1949	5	Trace	Fair	Fair	Fair	Trace	Fair	Fair	Poor	Fair	Good	Distal ends of sartorius and tensor to patella	45	2.0	Genu valgum		Poor
21	1946	3	0	Poor	Poor	Poor	0	Trace	Trace	Poor	Poor	0	Distal end of tensor to patella	42				Poor

turntable (Fig. 1). An electric motor with adjustable speed operates the movie camera at any desired speed from eight to sixty-four frames per second. The oscilloscopic traces are superimposed on the movie film so that each individual frame carries the oscilloscopic traces identical in point of time with the position of the subject shown (Fig. 2). It should be pointed out that the peak of electrical activity precedes the point of maximum muscle tension by approximately 0.08 second. The camera, oscilloscope, mirrors, and an auxiliary lens are mounted on a turntable. The turntable is rotated to photograph the patient who walks along a tangent to a circle centered at the camera.

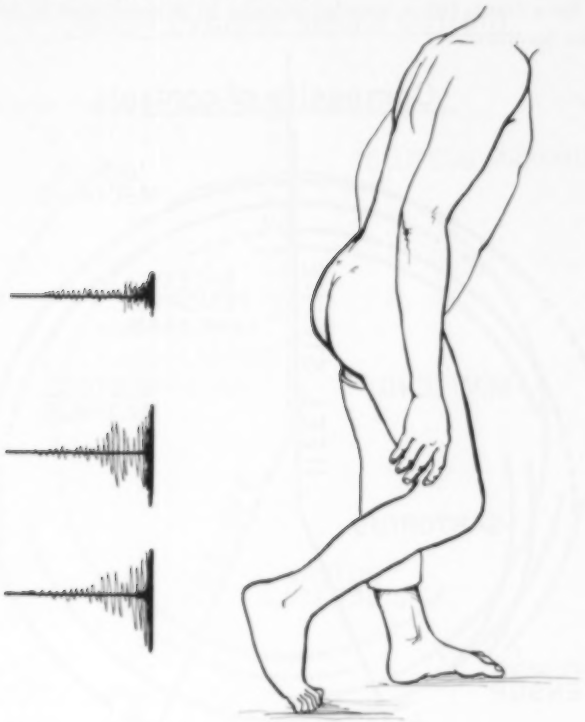


FIG. 2

Line drawing of representative movie frame showing a subject and the superimposed oscilloscope traces.

METHOD OF STUDY

Each child was questioned regarding his own opinion of the result after the transplantation. The parents were similarly interrogated. Manual muscle testing of the strength of the transplanted muscles and of the other muscles about the knee and hip was carried out on all patients. The muscles to be recorded were identified by manual testing. The skin overlying the muscle was infiltrated with 2 per cent xylocaine intracutaneously. Two electrodes of enamel-coated, No. 36 wire were placed in the muscle approximately one-half inch apart. The proper placement of the electrodes within the muscle was confirmed by stimulation as well as by visual and auditory monitoring of the electromyograph. The gain was then adjusted for each channel, and the voltage calibration was photographed. Movies were made of manual testing of the muscles as an additional means of confirming placement of the electrodes. Each child was then asked to walk barefooted in a normal fashion. The cable was suspended by an overhead

pulley to free the patient's arms. Instructions and other distracting influences were kept to a minimum to avoid alteration of each child's pattern of normal level walking. The camera was operated at a speed of sixty-four frames per second while the walking cycles were photographed. The frequency-response limits of the apparatus were eighty cycles to forty kilocycles per second. Shoes were then placed on the child, and the heel-toe-strike indicator was placed on the foot in question. An additional film was then made with the heel-toe-strike indicator lighting a neon bulb in the field of the camera at the moment of heel and of toe strike. In most instances the child returned for a second day of recording, and in many instances he returned for a third. Other muscles thought to be significant in knee stabilization were also recorded.

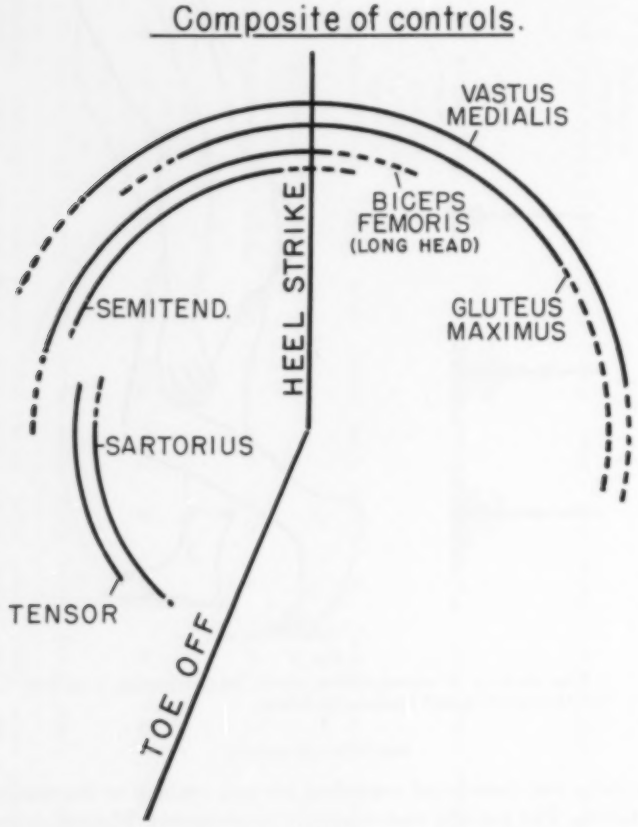


FIG. 3

Composite of mean cycles of normal control patients. Solid line = mean; dotted line = range. Vastus medialis: five subjects (one showed no activity). The vastus medialis was selected as representative of the quadriceps femoris. We found as did Inman and his group, that in normal level walking all portions of the quadriceps have essentially the same phasic activity. Gluteus maximus: six subjects (two showed no activity). Long head of biceps femoris: four subjects (one showed no activity). Tensor fasciae latae: three subjects (two showed no activity). Sartorius: four subjects (all demonstrated action potentials).

ANALYSIS OF DATA

Although general impressions could be formed from slow-motion projection, frame-by-frame analysis was essential for accuracy. For this purpose, a Bell and Howell time and motion-study projector was obtained. The frame counter was

found to be useful in the study of a single walking cycle. The points at which action potentials appeared and disappeared were observed and recorded. The points of heel strike and toe-off were determined both without shoes by visual means and with the heel-toe-strike indicator. In patients with no foot deformity and with a normal heel-toe gait there was no significant difference in determination of the heel strike and toe-off by the two methods. Some of the patients exhibited equinus contractures with altered weight-bearing patterns. For these patients, visual inspection of the photographic record was utilized to determine heel strike

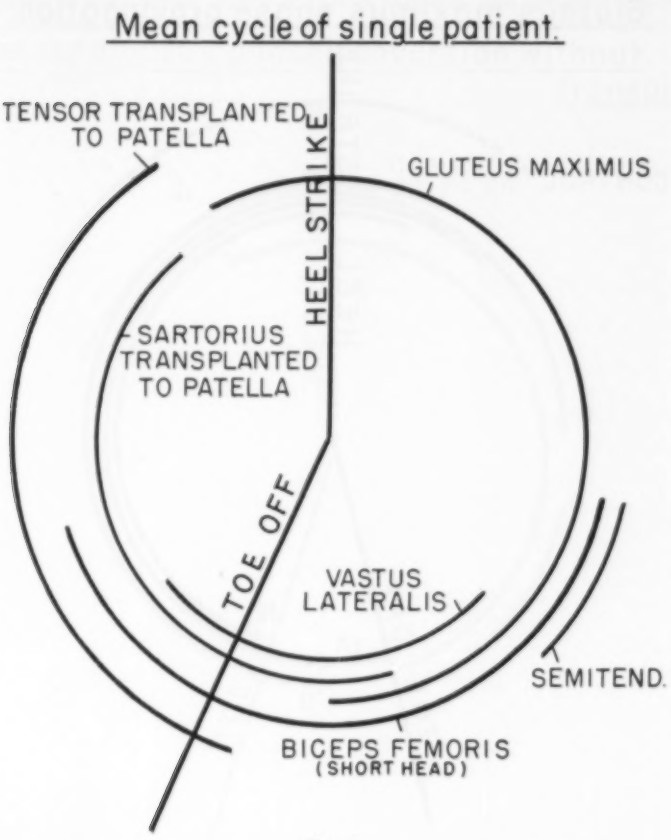


FIG. 4

The mean cycle of one patient with tensor and sartorius transplants. Note failure of conversion of sartorius and tensor to stance phase but prolongation of gluteus maximus and conversion of semitendinosus and short head of the biceps femoris to stance-phase activity. The patient exhibited excellent gait with no evidence of instability (Table I, Case 9).

and toe-off. The total number of frames in the walking cycle was determined, and the complete cycle was represented as 360 degrees by translating the frame indication to degrees and plotting the period of muscle activity on polar coordinate graph paper. Ten representative walking cycles were recorded for each muscle studied, and an arithmetical mean was determined for each muscle. This method of projection of the phasic activity of muscles makes comparison possible.

RESULTS

Six normal subjects were studied as controls. Figure 3 demonstrates the mean

activity and range of activity of the individual muscles tested in these control subjects. The muscles tested were the long head of the biceps femoris, vastus medialis, semitendinosus, gluteus maximus, tensor fasciae latae, and sartorius. It should be noted that in these normal control subjects the vastus medialis and gluteus maximus were active primarily in the stance phase but there is substantial extension activity into the late swing phase. The long head of the biceps femoris and the semitendinosus were active primarily in the late swing phase. The tensor and sartorius functioned in the early swing phase soon after toe-off.

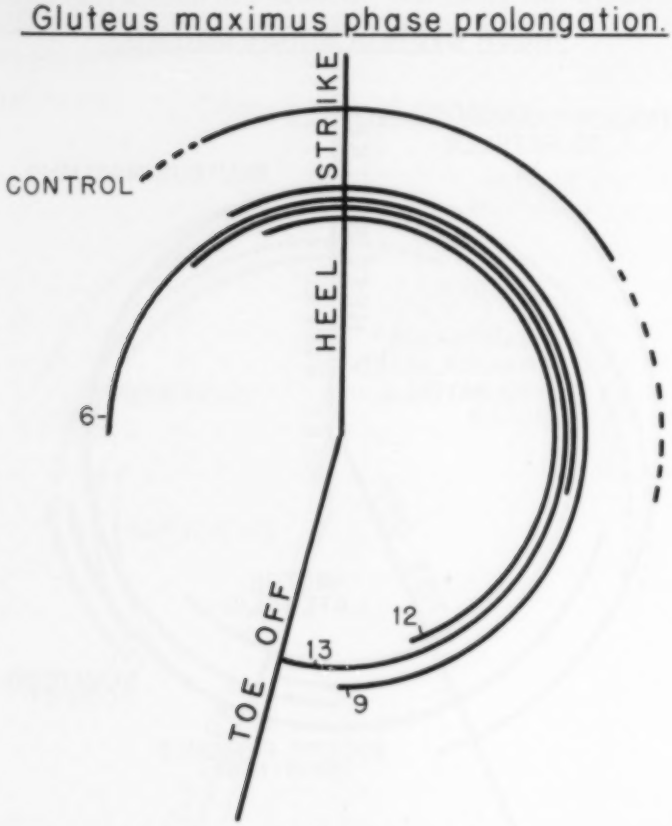


FIG. 5

Control study of the gluteus maximus in outer orbit to compare with the mean phasic activity of the gluteus maximus in four individual subjects with varying degrees of instability of the knee due to poliomyelitis. (See Table I.)

Many variations in phasic activity were observed in the patients with poliomyelitis. In patient H. K. (Fig. 4) the transplanted tensor and sartorius remained active in the swing phase, whereas the activity of the gluteus maximus extended through nearly all of stance and, in addition, there was conversion of the semitendinosus and the short head of the biceps femoris to late stance-phase activity. Figure 5 shows prolongation of the period of activity of the gluteus maximus in four patients with quadriceps insufficiency due to poliomyelitis. Figure 6 shows two instances of conversion of the semitendinosus to stance-phase activity in patients with poliomyelitis who have not had transplantation of the hamstrings. Substitution patterns in poliomyelitis are well known. Our electromyographic

studies confirmed the ability of the gluteus maximus and the hamstring muscles to alter their normal activity in apparent response to quadriceps weakness. The altered period of contraction of these muscles during gait appeared to be useful in stabilizing the knee. The phasic activities of the individual transplants are illustrated by composite graphs (Figs. 7 through 11). Of the patients studied in this group, ten of fourteen hamstring transplants were functioning in a phase grossly comparable to that of the quadriceps femoris (Figs. 7, 8, and 9). The pattern in each instance was remarkably constant, and no instances of regression to flexor phase patterns were noted. Eight of eleven sartorius and seven of twelve tensor

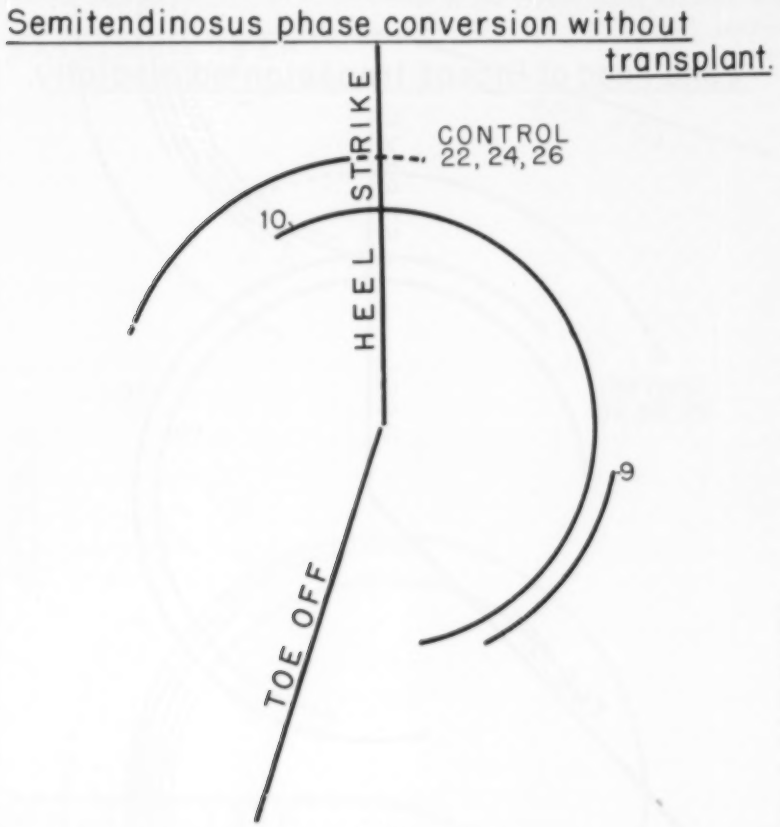


FIG. 6

Phase conversion of the semitendinosus in two subjects with quadriceps weakness due to poliomyelitis. In neither instance had the semitendinosus been transplanted. The mean and range of the semitendinosus controls are illustrated in the outer orbit (Table I).

transplants functioned during the swing phase (Figs. 10 and 11). The contraction of these transplants occurred during the period of time that the hip and knee were flexing, and there was electrical silence throughout the stance phase. A number of patients in this group walked very well; however, we found in these instances prolongation of gluteus maximus activity, or conversion of the hamstrings to stance-phase activity, or both of these changes. The poor conversion rate of the sartorius and tensor transplants as well as the relatively poor clinical results after these transplants led us to re-evaluate their function. The hamstring transplants after insertion of the distal ends into the patella continued to function as hip

extensors in addition to their new function as extensors of the knee. In normal walking, hip and knee flexion occur during swing phase, and hip and knee extension occur principally during stance phase. The alteration of the insertions of the tensor and sartorius add knee extension to their function as hip flexors; these are not complementary functions in walking, and it is not surprising that a single function of the transplanted muscle is selected in walking. It appears that after transplantation the sartorius and tensor transplants frequently functioned only as hip flexors in normal walking, failing to convert to the desired stance-phase activity. The question then arose as to whether it would be possible to achieve a more constant phase conversion of these muscles by eliminating their hip-flexion function.

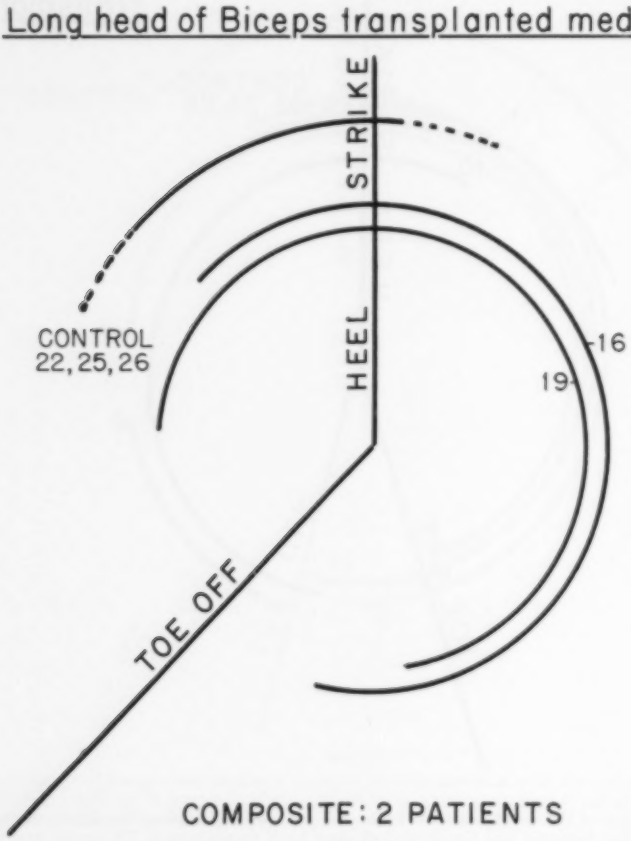


FIG. 7

Fig. 7: Excellent stance-phase conversion of two transplants of the long head of the biceps femoris medially after the manner of Caldwell is shown. The phasic activity of the normal controls is illustrated in the outer orbit (See Table I).

FIG. 8

Fig. 8: A composite of five subjects with lateral transplantation of the long head of the biceps to the patella is shown along with the normal controls. Two additional subjects showed no activity of the transplants. Four of the transplants illustrate significant extension into the stance phase. One of these four continues on half-way through the swing cycle (Table I).

FIG. 9

Fig. 9: Four of the five subjects with medial transplantation of the semitendinosus to the patella illustrate significant extension into the stance phase. The fifth was considered predominantly swing phase, although it exceeds even the range of the control subjects (Table I).

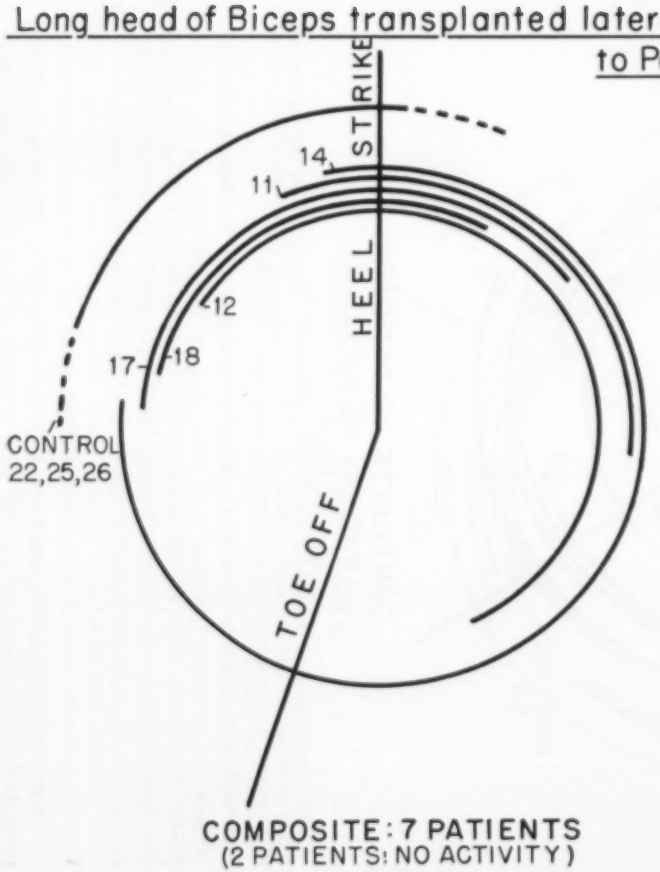

Long head of Biceps transplanted laterally to Patella.
STRIKE
HEEL
TOE OFF
14
11
12
17
18
CONTROL
22,25,26
COMPOSITE: 7 PATIENTS
(2 PATIENTS: NO ACTIVITY)

FIG. 8

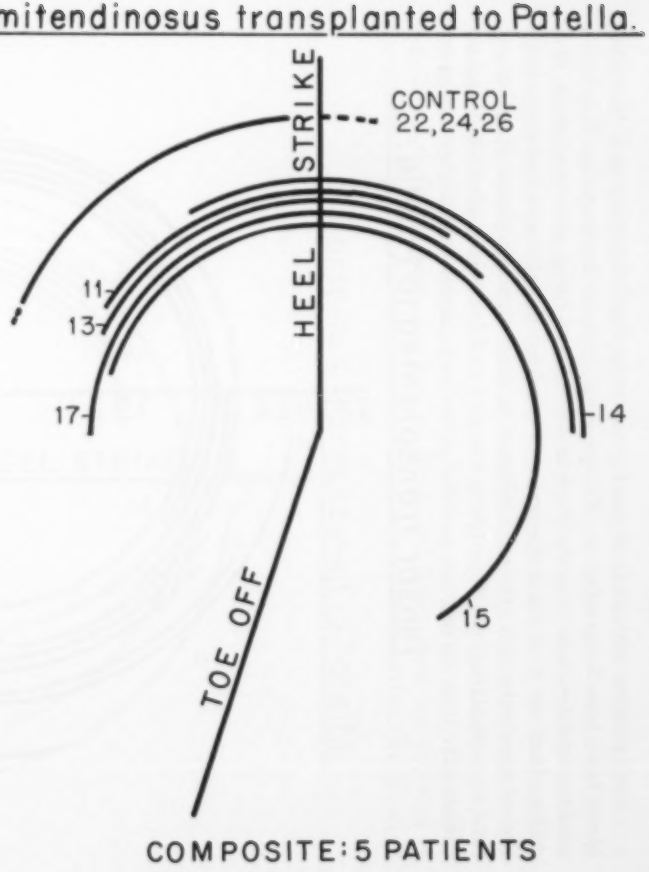

Semitendinosus transplanted to Patella.
STRIKE
CONTROL
22,24,26
HEEL
11
13
17
14
15
TOE OFF
COMPOSITE: 5 PATIENTS

FIG. 9

Four patients with sartorius and tensor transplants functioning in the swing phase have been reoperated on. The proximal ends of the sartorius and tensor muscles were detached from the ilium and secured to the greater trochanter, thus making both the tensor and the sartorius one-joint muscles with the single function of knee extension. On an additional patient with quadriceps insufficiency, total transplantation of the sartorius was performed. To date, electromyographic studies have been carried out on three of the transplants on which second operations were performed. In all three transplants the signal was low, but the electromyographic sampling indicated that their activity had changed to the stance phase (Figs. 12, 13, and 14). The period of time since reoperation in each instance was approximately two months. Further time and additional studies are necessary before conclusive evidence of alteration of function can be presented.

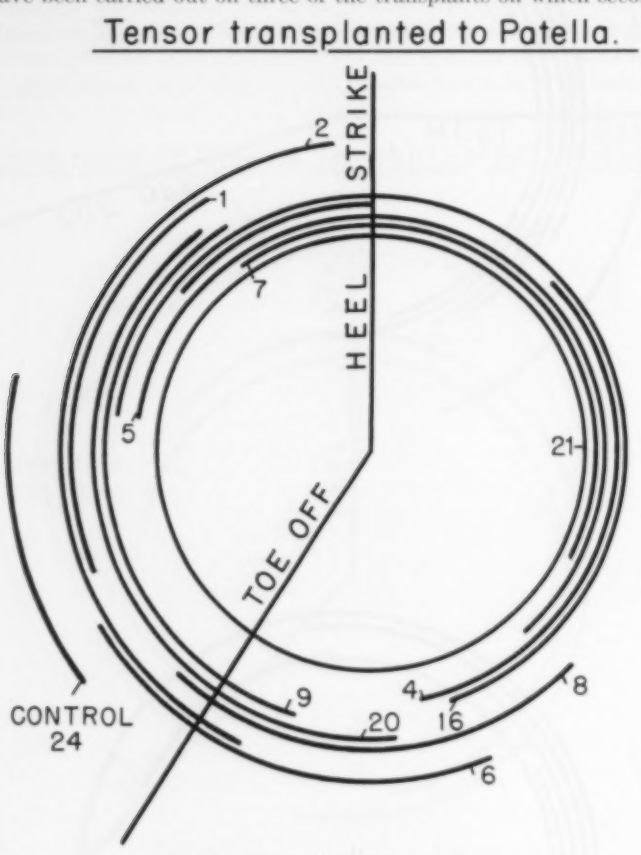


FIG. 10

Tensor fasciae latae to the patella (eleven transplantations). Comment: One patient showed action potentials through the entire walking cycle. Four transplants showed significant stance-phase activity; the remainder functioned during swing phase (Table I).

DISCUSSION

Weiss and Brown described ultimate conversion of all the biceps femoris transplants to stance-phase activity after a period of time that was not clearly

outlined. They postulated voluntary overriding of the innate reflex patterns of activity. They observed reversions to the old phase under conditions of fatigue or lack of concentration. Close and Todd found a low incidence of conversion of the biceps femoris to stance-phase activity after transplantation. In our series, which is admittedly small, the conversion rate in the hamstring transplants appears to be higher than that reported by Close and Todd. It is of interest that not one transplant of a single hamstring failed to show a conversion to stance phase. The regressions to flexor phase described by Weiss and Brown were not observed in our studies. The children were not under observation for more than two hours at

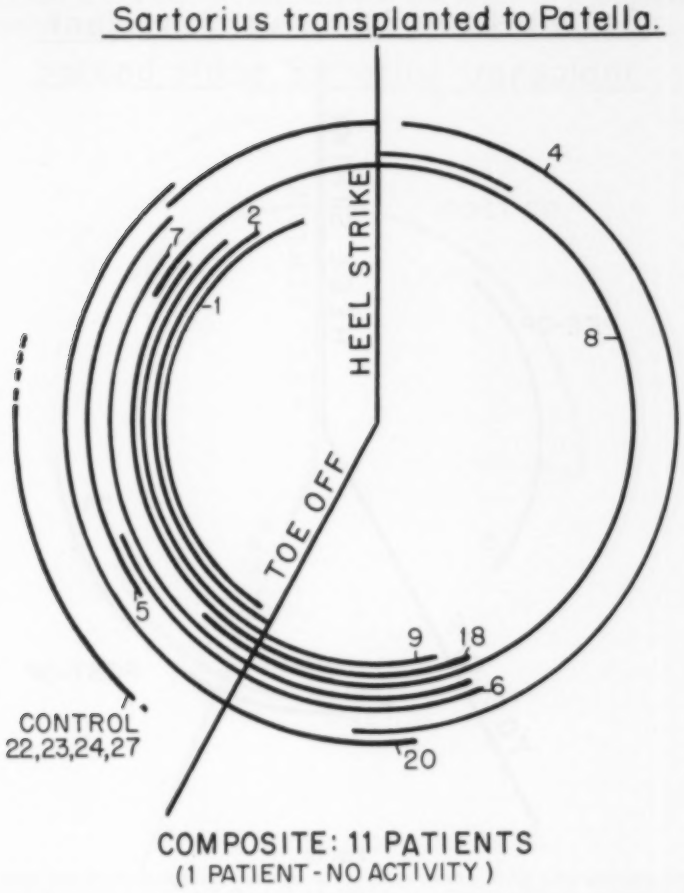


FIG. 11

Sartorius to the patella (eleven transplants). Comment: Of this entire group only two transplants showed significant stance-phase activity; eight functioned during swing phase (Table I).

a time, and the possibility of alteration of phase conversion caused by fatigue was not explored. The patients included in our study received no formal re-education of the transplanted muscles. It was the conviction of one of us (F. C. B.) that if a transplant was indicated and the procedure was performed properly with adequate protection in the early postoperative period, little re-education was necessary. The conversion rate of the sartorius and tensor transplants was disappointing. We believe that this may very well be due to the presence of local

mechanical factors rather than to the offending of any innate reflex pathways by the transplant. The changing of the distal insertions of these muscles alone did not sufficiently alter their function to bring about conversion. Surgical alteration to give single-joint function has, on the contrary, in a limited number of cases, resulted in phase conversion when transfer of only the distal ends had failed. Our follow-up period is not sufficient to give valid information regarding the function of these transplants other than their phase conversion.

Phase conversion in transplants has too frequently been attributed to the single factor of relearning or recontrol of the transplanted muscle. The tendency

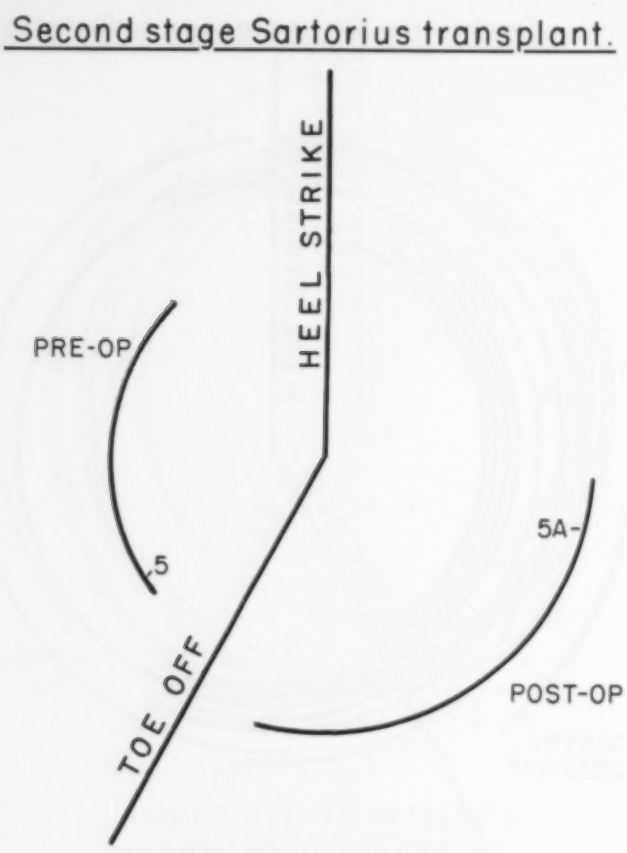


FIG. 12

The preoperative orbit gives a mean cycle of the sartorius transplant three and three-quarters years after attachment of the insertion to the patella. *Note:* Failure of conversion of the transplant to any significant stance-phase activity. The postoperative orbit illustrates the mean phasic activity of the same transplant after release of the origin and reattachment to the trochanter. The postoperative recording is approximately two months after the operation (Table I).

has been to assume that the function desired has been achieved when, under voluntary control in a given position, a movement can be performed. Should the transplant fail to convert to the desired phase in walking, the offending of reflex pathways in the central nervous system is blamed. The presence of frequent phase alterations without surgery in the patient with poliomyelitis casts serious doubt on this hypothesis. It appears to us from this limited study that the optimum use of the available muscle motors, transplanted or untransplanted, does not tax the

central nervous system of a patient with old poliomyelitis. The various patterns of paralytic gait have been studied by many clinicians. A proper knowledge of these patterns coupled with a knowledge of the functional behavior of the individual muscles derived from electromyographic studies should, in time, elucidate the likelihood of phase conversion in a given set of circumstances and should direct us to other factors that may influence phase conversion. Some of these factors may be the quality of the muscle or its strength before transplantation, the patient's need for the transplant, the presence or absence of other compensating mechanisms that can accomplish a given function, the tension under which the transplant is attached, the relationship of this tension to a particular range of movement, and perhaps many other factors unknown to us.

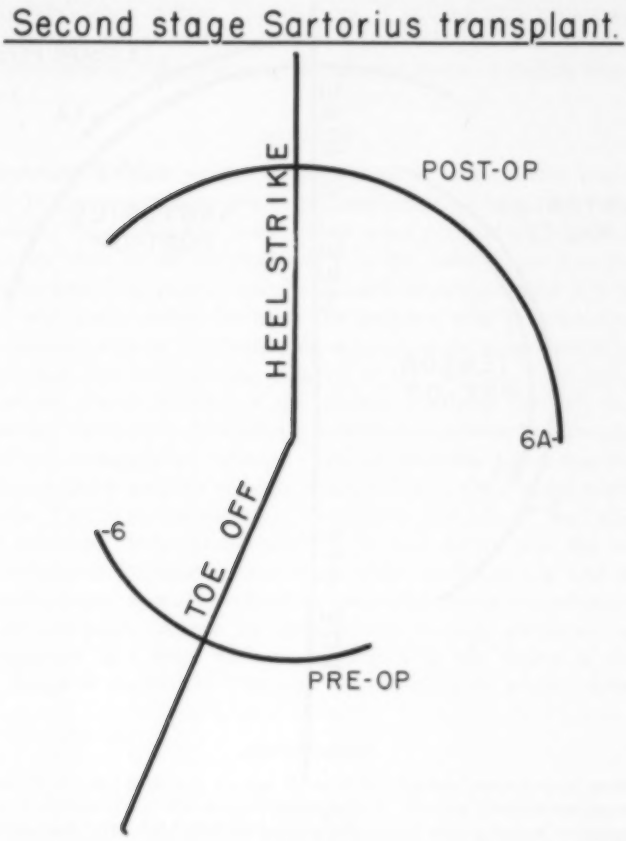


FIG. 13

The preoperative cycle demonstrates minimum late stance-phase activity with extension into swing two years after transfer of the insertion of the sartorius into the patella. The postoperative record illustrates the mean phasic activity of the sartorius transplant two months after detachment of the sartorius origin and reattachment to the greater trochanter. The phasic activity now closely approximates that of the normal quadriceps femoris. Since the final operation the patient gets along well with a knee-to-ankle brace (Table I).

No discussion of phase conversion would be complete without reference to the theories of reciprocal innervation and the automatic reflex nature of normal level walking. Both of these theories can be traced to Sherrington, whose description of the stepping reflex in man was derived from his study of decerebrate and spinal animals. Although the thinking of many physiologists revolves about his theories,

it should be noted that he, himself, cautioned against direct comparisons between man and the lower animals as indicated in the following quotation: "Studied in that self-contained animal group, the Vertebrates, the behaviour seems to become less and less reflex as the animal individual becomes more and more complexly individuated. The 'spinal' man is more crippled than the 'spinal' frog".

It appears to us that since there is far greater voluntary control of the musculoskeletal system in man than in any of the animal species, it is quite unjustified to use reflex behavior of spinal or decerebrate animals to explain the complexities of locomotion in man.

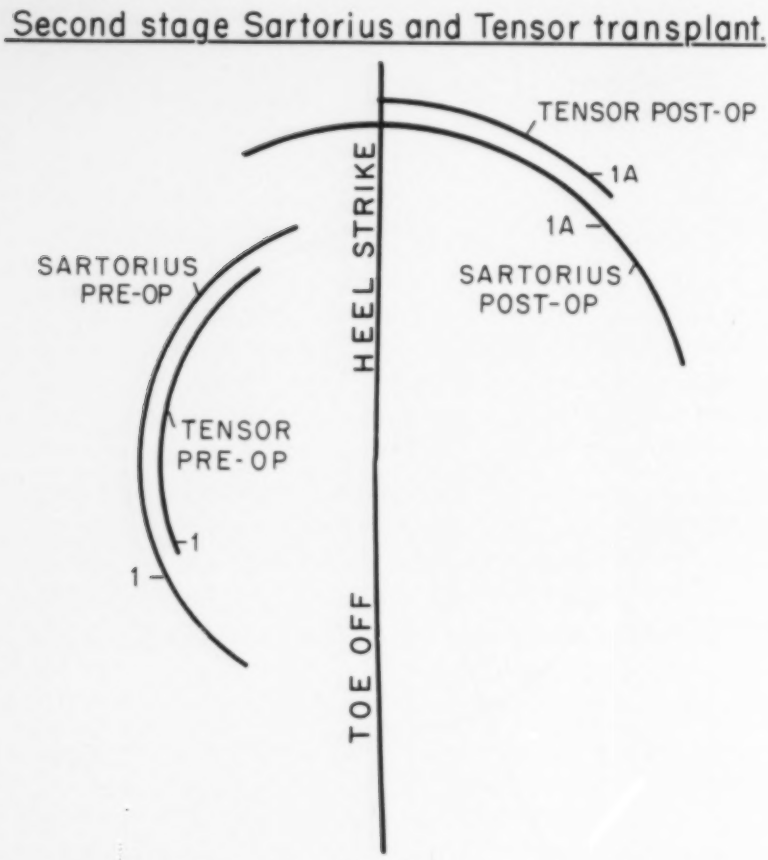


FIG. 14

The preoperative sartorius and tensor swing-phase activity six years after the insertions of sartorius and tensor were transferred to the patella. Postoperative tensor and sartorius approximately two months after the release of the origins of the sartorius and tensor and reattachment to the greater trochanter. Toe-to-groin brace was eliminated after the last operation. Phase conversion approximating quadriceps is apparent (Table 1).

According to the principle of reciprocal innervation, augmentation of muscle contraction never proceeds concurrently in antagonistic muscles, and, similarly, diminution of contraction in antagonists does not occur concurrently. Ralston and Libet, working with the University of California Biomechanics Group, questioned the validity of this theory. They stated that there is no denying the existence of reciprocal inhibition in certain experimental or pathological conditions, nor did they exclude the possibility that reciprocal innervation may play a sig-

nificant role in the normal animal operating to modify excitatory and inhibitory levels of appropriate neurons. However, in overt motor patterns, such as locomotion in normal man, their group found that during parts of the walking cycle, augmentation and diminution of contraction actually do proceed concurrently in anatomically antagonistic muscles, for instance, in the pretibial and calf groups, in the quadriceps and hamstring groups, and in the abductor and adductor groups. They believed that such evidence would seem to contradict directly the general application of the principle of reciprocal inhibition and would seem to exclude reciprocal innervation as the dominating factor in all motor patterns.

The balance that exists between the voluntary control of muscles in the lower extremities and the control by reflexes arising in proprioceptive receptors has yet to be clearly established in man. Furthermore, if walking were principally a reflex automatic activity, as has been postulated [9], the ability of man to accommodate to altered problems in locomotion by acquired reflexes or habits must be very great indeed.

SUMMARY

An electromyographic study is presented of twenty-one patients with paralysis of the lower extremity due to poliomyelitis on whom thirty-nine muscle transplantations for quadriceps insufficiency were performed. Electromyograms and gait movies were filmed simultaneously on the same movie film by specially designed apparatus. The phasic activity of each muscle studied was plotted on polar coordinate graph paper, for both the patients with poliomyelitis and for six normal control subjects. Numerous phase conversions were evident in both the transplanted and non-transplanted muscles in the patients with poliomyelitis. Extension of the phasic activity of the gluteus maximus through most of the stance phase and conversion of hamstring activity from swing to stance phase were observed in non-transplanted muscles. Ten of fourteen hamstring transplants achieved stance-phase activity roughly comparable to that of the normal quadriceps femoris. Two of eleven sartorius transplants and four of the twelve tensor transplants achieved stance-phase activity. It was noted that the tensor and sartorius transplants frequently functioned while both the hip and knee were flexing. A preliminary report is made of sartorius and tensor transplants that were converted to one-joint muscles by detachment of their proximal ends from the anterosuperior iliac spine with reattachment in the region of the greater trochanter. Some of the factors that may have bearing on phase conversion are discussed.

REFERENCES

1. Broderick, T. F., Jr.; Reidy, J. A.; and Barr, J. S.: Tendon Transplantations in the Lower Extremity. A Review of End Results in Poliomyelitis. II. Tendon Transplantations at the Knee. J. Bone and Joint Surg., **34-A:** 909–914, Oct. 1952.
2. Caldwell, Gene: Transplantation of the Biceps Femoris to the Patella by the Medial Route in Poliomyelitic Quadriceps Paralysis. J. Bone and Joint Surg., **37-A:** 347–353, Apr. 1955.
3. Close, J. R., and Todd, F. N.: The Phasic Activity of the Muscles of the Lower Extremity and the Effect of Tendon Transfer. J. Bone and Joint Surg., **41-A:** 189–208, Mar. 1959.
4. Kuhlman, R. F., and Bell, J. F.: A Clinical Evaluation of Tendon Transplantations for Poliomyelitis Affecting the Lower Extremities. J. Bone and Joint Surg., **34-A:** 915–926, Oct. 1952.
5. National Research Council, Advisory Committee on Artificial Limbs, Prosthetic Devices Project: The Pattern of Muscular Activity in the Lower Extremity during Walking. Series II, Issue 25, September 1953. Berkeley, University of California, Institute of Engineering Research, 1953.
6. Ralston, H. J., and Libet, B.: The Question of Tonus in Skeletal Muscle. Am. J. Phys. Med., **32:** 85–91, 1953.
7. Scherb, Richard: Kinetisch-diagnostische Analyse von Gehstörungen: Technik und Resultate der Myokinesigraphie. Zeitschr. Orthop., Band 82, Supplementum. Stuttgart, F. Enke, 1952.

8. SCHWARTZMANN, J. R., and CREGO, C. H., JR.: Hamstring-Tendon Transplantation for the Relief of Quadriceps Femoris Paralysis in Residual Poliomyelitis. A Follow-up Study of 134 Cases. J. Bone and Joint Surg., **30-A**: 541-549, 559, July 1948.
9. SHERRINGTON, CHARLES: The Integrative Action of the Nervous System. With a New Foreword by the Author and a Bibliography of His Writings, pp. xiv and 420. Cambridge, Cambridge University Press, 1947.
10. SMART, B. W.; BLOSSER, J. A ; and CLOSE, J. R.: Electromyography in Normal and Transplanted Muscles of the Lower Extremity. J. Bone and Joint Surg., **38-A**: 433, Apr. 1956.
11. STEINDLER, ARTHUR: A Historical Review of the Studies and Investigations Made in Relation to Human Gait. J. Bone and Joint Surg., **35-A**: 540–542, 728, July 1953.
12. WEISS, PAUL, and BROWN, P. F.: Electromyographic Studies on Recoördination of Leg Movements in Poliomyelitis Patients with Transposed Tendons. Proc. Soc. Exper. Biol. and Med., **48**: 284–287, 1941.

DISCUSSION

DR. I. V. PONSETI, IOWA CITY, IOWA: The alteration of the phasic activities of the hamstrings and the gluteus maximus found by the authors in patients with poliomyelitis who had no tendon transfers is of interest. This finding corroborates the common clinical observation that the hamstrings and the gluteus maximus, together with the gastrocnemius, serve as stabilizers of the knee in patients with paralyzed quadriceps.

The authors have corroborated the observation made by Weiss and Brown, in 1941, that phasic conversion often occurs in transferred hamstring muscles. A correlation has been found between the phasic conversion and the subjective improvement of the patient. The lack of phasic conversion of the transferred sartorius and tensor fasciae latae is of interest and helps to explain the failure often observed after the transfer of these muscles in quadriceps weakness.

These observations on electromyography of transferred muscles are of interest. However, only two electrodes were placed in the muscle, one-half inch apart. Differences in the duration of potentials recorded in different points of the muscle occur and are due partly to differences in the extent of the innervation zones for different motor units and partly to a different position of the recording electrode relative to these zones.

I doubt that preoperative electromyographic studies would be of great help in deciding indications for hamstring transfers. The dynamics of gait are extremely complex, and the infinite diversity of paralysis in patients with poliomyelitis makes a mathematical evaluation of pathological gait nearly impossible. For a long time to come we will have to rely on clinical judgment and experience for our indications for tendon transfers.

In the past twenty years, hamstring transfers for quadriceps weakness were done in only ten patients with poliomyelitis in the Orthopaedic Department at the State University of Iowa. Most of them had satisfactory results. Patients with paralysis of the quadriceps and strong glutei, hamstrings, and gastrocnemius usually walk well, although often with the knee in 15 to 20 degrees of flexion and with a short step. With training, the posterior stabilizing mechanism of the knee, formed mainly by the hamstrings and gastrocnemius soleus can often be improved sufficiently to obviate an operation. The mild flexion of the knee should not be corrected in these cases. Hamstring transfers, when well indicated, allow for better utilization of the double pendulum action in the swing phase, with saving of energy, and often provide for a longer step and safer gait.

DR. LEO MAYER, NEW YORK, N. Y.: I want to congratulate Dr. Sutherland and his co-workers on their ingenuity in helping to solve one of the difficult problems associated with tendon transplants—the conversion of the transplant from one phase of gait to another. Unfortunately, one of those co-workers, our deeply beloved Toby Bost, is no longer with us, but this paper will live, as will his memory, to encourage us as orthopaedic surgeons to improve the science and the art of our specialty.

Under local anesthesia the authors inserted two electrodes into the muscle to be tested. Then, as the child walked, electromyographic recordings were made and movies were made at the rate of sixty-four frames per second. To record the swing and stance phases, shoes were worn with a heel-toe-strike indicator lighting a neon bulb. In addition, manual muscle tests were made as well as inquiry into the degree of subjective improvement after the transplant. By use of a Bell and Howell time and motion-study projector it was possible to determine the exact points at which action potentials appeared and disappeared. These observations could be translated into degrees and recorded on polar coordinate graph paper.

The experiments showed that in many, although in not all, of the transplants there developed a marked change in the phasic activity so as to resemble the phasic activity of the paralyzed quadriceps. This was particularly true of the semitendinosus (five cases) and of the biceps (two cases) transplanted by the medial route. Of seven biceps transplanted by the lateral route, four achieved stance-phase activity, two showed no electrical activity, and one showed activity only

in the late swing phase with minimum extension into the stance phase. Of eleven tensor fasciae latae transplants, only four showed significant stance-phase activity, the others showed swing-phase activity. Of the sartorius transplants, only two showed conversion of phasic activity. The good results in the hamstring transplants are the more remarkable because formal muscle re-education was not attempted. In other words, the knee flexors were readily converted into active substitutes for the quadriceps.

It must, however, be emphasized that this paper is concerned only with one aspect of tendon transplantation—the conversion of phasic activity. Other aspects are of equal importance, namely, the relative strength of the transplants; the length of the muscle fibers, which so largely determines the range of contractility; the technique of the tendon fixation; the degree of tension applied to the tendon, the direction of the transplant; and the best method of avoiding the danger of lateral displacement of the patella.

In my own study of quadriceps replacement, based purely on empirical methods, I have achieved good results by utilizing the biceps with one of the medial hamstring group. The direction of the tendons must be nearly vertical; if they run horizontally they will pull the patella in a posterior direction. Dr. Fremont Chandler's operation of shortening the patellar tendon in patients with cerebral palsy applied to these transplants has added markedly to the effectiveness of the quadriceps replacement.

Dr. Schottstaedt (closing): Normal gait is that method of locomotion most generally studied. It has been our purpose to study abnormal gait, which, because of paralysis and certain mechanical factors, may be carried out with an altered sequence of muscle contraction. Many patients have insisted that their gait was improved following certain surgical procedures. We were anxious to know if there was a physiological basis for this and what it might be rather than to insist that a muscle transplant could not convert to a new action time and therefore could not successfully replace another muscle in the gait pattern.

The findings showed, as just reported, that surgery may not be necessary to change a hamstring in phase if functional demands alone are optimum. Therefore, the occurrence of a proper phase relationship with the hamstrings when transplanted was not too startling. The results of transfer of the insertion of the tensor and the sartorius were equivocal in this study; some were good, others were not. Those not good were also not clinically satisfying. For this reason, four of these were chosen to see if an altered surgical plan would prove the theory, changing phase and improving clinical results.

It seemed theoretically necessary to change the tensor and sartorius transplant so that hip flexion would not be a prime motor function. The surgical procedure used transfers the origins of both the tensor and sartorius to the greater trochanter. This accomplishes, in effect, a two-stage total muscle transposition—perhaps better done in one stage.

Technically, the procedure is not difficult on the sartorius; that on the tensor is much more difficult, although in time it can be refined. The early postoperative follow-up indicates a change in phase as well as clinical improvement.

This report is admittedly premature but so exciting that we need to at least mention it. Furthermore, the improvement of this surgical procedure illustrates a very useful clinical application of the electromyograph, both in studying and in planning clinical work.

Tetracycline Fluorescence in Bone Lesions

Preoperative Tetracycline Administration for the Identification of Abnormal Tissue during Operation and Tetracycline Concentration in Certain Bone Lesions *

BY JOHN F. McLEAY, M.D., AND BENEDICT R. WALSKE, M.D., OMAHA, NEBRASKA

From the Department of Surgery, Creighton University School of Medicine, Omaha

Concentration of tetracycline in rapidly growing tissue, particularly in bone, has been observed by several authors [1,5,6,7,9,10]. This phenomenon is manifested by a golden-yellow fluorescence visible when the bone is placed under ultraviolet light. The reason for the concentration of the tetracycline in any rapidly growing tissue is not known. In a previous report [5], tetracycline concentrations in all forms of neoplasms, including bone, were determined. It was noted that all types of tissue exhibiting rapid growth concentrate the tetracycline, but bone tumors show the greatest concentrations. The object of this paper is to record the concentrations of tetracycline within certain bone lesions and within areas of normal bone growth, indicating the potential value of preoperative administration of tetracycline as an aid in identifying neoplastic tissue.

METHODS AND MATERIALS

Drug Used

Terramycin was used as the tetracycline in this experiment. Each patient received fifteen milligrams per kilogram of body weight per day in divided doses, given intravenously in 100 cubic centimeters of saline solution for three or more days before surgery. This dosage produces a peak blood level of about ten micrograms per milliliter [8,11]. Administration of the drug was discontinued at least twelve hours, preferably twenty-four hours, before surgery, to allow the tetracycline to be removed from the normal mature tissues, but to be retained in the neoplastic and rapidly growing tissue.

Procurement and Storage of Tissue

The source of light was an ultraviolet, 100-watt lamp, emitting light of 3,660 angstroms. This light was placed approximately eighteen inches from the bone after it had been exposed at operation; the ultraviolet lamp was the only source of light in the operating room. Under these conditions, a bone lesion appears as a sharply demarcated yellow-fluorescent area. Once the lesion had been located by this method, the overhead lights of the operating room were turned on, and a biopsy was obtained. Biological assays were performed on the fresh surgical specimens and also delayed studies were performed six months later. The fluorescent intensities of the lesion decreased after storage for six months at −10 degrees centigrade, but the bacteriostatic activity of the tissue so stored showed only slight change. These specimens were allowed to thaw to room temperature (approximately four hours) before they were restudied.

Biological Assay

The tissue removed at surgery was pulverized by use of a pestle and mortar.

*This research was supported in part by a grant from the National Cancer Institute.

The contents were then transferred to a beaker and diluted one to ten by volume, with a monobasic potassium-phosphate buffer, pH 4, as the extracting solution. A cylinder method of assay [3] was used in the determination of the level of tetracycline in each specimen. Petri dishes were prepared by covering a hardened base layer of agar with a layer of agar inoculated with *Bacillus cereus*, var. *mycoides*, which served as the test organism. Six steel cylinders, evenly spaced, were placed in the solid inoculated agar of each plate. Three cylinders were filled with the sample (supernate), and three cylinders were filled with standard concentrations of tetracycline—alternate cylinders being filled with standard and sample. Three plates were used for each determination. After an incubation period of eighteen hours at 30 degrees centigrade, clear zones of inhibited growth were demonstrated. The diameter of these zones was measured, and the difference between the diameter of the zone of the standard and that of the test sample was determined. From a standard curve that employed the concentration in micrograms per cubic centimeter as the ordinate and the diameter of the zone of inhibition as the abscissa, the concentration of tetracycline in micrograms per gram of tissue was determined for each sample.

Photography

It was difficult to obtain good color photographs of the yellow-fluorescing tumors under ultraviolet light. However, by use of daylight Kodachrome film, with a 3,660-angstrom ultraviolet light as the only light source placed twelve inches from the tissue, a four-minute exposure, and an F-11 aperture of the lens, we were able to obtain adequate color photographs.

RESULTS

One specimen from a patient with osteitis deformans, five tumors of bone, and a control group that included tissue from patients with osteomyelitis, ununited fractures, and fresh fractures were studied. The results are summarized in Table I.

DISCUSSION

From the data obtained it is apparent that any rapidly growing bone tends to concentrate the tetracycline.

The concentrations of tetracycline in the malignant conditions of bone averaged approximately twenty-five micrograms per gram of tumor, whereas in the control group of bone lesions the concentrations were in the range of one to four micrograms per gram in the reactive, or new, bone at the site of the defect. In one patient, J. H. (Table I), previous x-ray therapy to the Ewing tumor did not reduce the tetracycline concentration to levels comparable with those in the control group. Bone specimens, stored at −10 degrees centigrade for six months still showed fluorescence, but to a lesser degree than fresh specimens; the bacteriostatic activity of the stored tissue showed only a slight decrease after storage.

Fluorescence of malignant bone lesions under ultraviolet light when tetracycline has been given before operation may be of value at operation as an aid in localizing the neoplastic tissue. It is important that all lights in the operating room except the ultraviolet light should be off during the selection of the biopsy site and the determination of the extent of the lesion.

Possible application of the concentration of tetracycline in malignant conditions, in general, and in bone tumors, in particular, are currently being investigated in animals; the tetracycline is used as the vehicle and it is united with radioactive iodine (I-131) [2]. Tetracycline combined with I-131 may be of diagnos-

TABLE I

TETRACYCLINE FLUORESCENCE IN BONE LESIONS

Patient	Age (*Years*)	Race	Sex	Diagnosis	Fluorescent Areas	Tetracycline Concentration (*Micrograms per Gram of Tumor*)
Tumors and Osteitis Deformans:						
C. B.	27	Negro	F	Osteogenic sarcoma, right femur	Brilliant-yellow fluorescence in the tumor in the bone marrow and in the direct extensions of the tumor along the periosteal surface and into the surrounding muscles; the normal reactive bone showed a yellow fluorescence, whereas the remaining normal mature bone showed blue autofluorescence	(Not determined)
J. H.	15	Caucasian	M	Ewing's tumor, left radius	Brilliant-yellow fluorescence in the tumor in the bone marrow and in the direct extensions of the tumor along the periosteal surface and into the surrounding muscles; the normal reactive bone showed a yellow fluorescence, whereas the remaining normal mature bone showed blue autofluorescence	20; 18 (six mos. later)
W. H.	16	Caucasian	M	Periosteal osteogenic sarcoma, left tibia	Brilliant-yellow fluorescence in the tumor and its direct extensions into the surrounding muscles; the normal reactive bone showed a yellow fluorescence, whereas the remaining normal mature bone showed blue autofluorescence	30; 27 (six mos. later)
R. C.	14	Caucasian	F	Osteogenic sarcoma, right tibia	Brilliant-yellow fluorescence in the tumor and its direct extensions along the marrow cavity and the periosteal surface, and into the	28; 25 (six mos. later)

					surrounding muscles; the normal reactive bone showed a yellow fluorescence, whereas the remaining normal mature bone showed blue autofluorescence	
C. A.	60	Caucasian	M	Chondrosarcoma, left femur	Yellow fluorescence in the surrounding reactive bone and a dull-yellow fluorescence of the tumor tissue and possibly of the normal reactive new bone remaining within the tumor	24; 23 (six mos. later)
R. S.	71	Caucasian	M	Osteitis deformans, right ilium	Brilliant-yellow fluorescence in all the exposed bone; biopsy not done	(Not determined)
Control Group:						
D. C.	40	Caucasian	F	Osteomyelitis, right tibia, of 6 mos. duration	Yellow fluorescence in the reactive bone around the defect; the surrounding normal mature bone showed blue autofluorescence	2 (at the defect site)
R. H.	20	Amerind	F	Osteomyelitis, right ilium, of 4 mos. duration	Yellow fluorescence in the reactive bone around the defect; the surrounding normal mature bone showed blue autofluorescence	1 (at the defect site)
R. S.	35	Amerind	M	Osteomyelitis, left tibia, of 1 yr. duration	Yellow fluorescence in the reactive bone around the defect; the surrounding normal mature bone showed blue autofluorescence	3 (at the defect site)
A. K.	20	Caucasian	M	Non-union of left radius, of 6 mos. duration	Yellow fluorescence of the new bone at the site of non-union; the adjacent bone showed blue autofluorescence	1 (at the fracture site)
T. S.	45	Caucasian	M	Non-union of tibia, of 12 mos. duration	Yellow fluorescence of the new bone at the site of the defect; the adjacent normal mature bone showed blue autofluorescence	2 (at the defect site)
Q. J.	30	Caucasian	M	Fracture of radius, of 1 wk. duration	Yellow fluorescence of the new bone at the site of the defect; the adjacent normal mature bone showed blue autofluorescence	1 (at the defect site)

tic and, possibly, therapeutic, value for neoplasms, especially bone tumors.

CONCLUSIONS

Tetracycline, administered intravenously, in divided doses of fifteen milligrams per kilogram of body weight per day for three or more days before operation, is deposited in bone lesions in such concentration that the malignant tissue will exhibit brilliant-yellow fluorescence under ultraviolet light in the operating room. This fluorescence can, therefore, be used in the detection and location of malignant tissue.

Rapidly growing bone also concentrates the tetracycline, but to a lesser degree.

In the malignant lesions that were studied in this series, the concentration of tetracycline was approximately six-fold greater than that in normal new bone. After the tetracycline is in the bone it maintains its fluorescence and bacteriostatic activity up to six months in specimens kept at −10 degrees centigrade.

Tetracycline combined with radioactive iodine (I-131) may prove to be of diagnostic and therapeutic value for neoplasms, especially malignant conditions of bone.

REFERENCES

1. Anderson, R. L., Jr.; Ferguson, A. B., Jr.; and Braude, A. I.: Bacteriostasis of Tetracycline Deposited in Bone. Surg., Gynec., and Obstet., **108**: 65–67, 1957.
2. Dunn, A. L.; Eskelson, C. D.; McLeay, J. F.; Ogborn, R. E.; and Walske, B. R.: A Biological Study of a Radioactive Product Obtained from Iodinating Tetracycline. Proc. Soc. Exper. Biol. and Med., **104**: 12–13, 1960.
3. Grove, D. C., and Randall, W. A.: Assay Methods of Antibiotics—A Laboratory Manual. Antibiotics Monograph No. 2. New York, Medical Encyclopedia Inc., 1955.
4. Lane, M.: Personal communication.
5. McLeay, J. F.: The Use of Systemic Tetracyclines and Ultraviolet in Cancer Detection. A Preliminary Report. Am. J. Surg., **96**: 415–419, 1958.
6. Milch, R. A.; Rall, D. P.; and Tobie, J. E.: Bone Localization of Tetracyclines. J. Nat. Cancer Inst., **19**: 87–93, 1957.
7. Milch, R. A.; Rall, D. P.; and Tobie, J. E.: Fluorescence of Tetracycline Antibiotics in Bone. J. Bone and Joint Surg., **40-A**: 897–910, July 1958.
8. Musselman, M. M., and Davis, H. L.: Antimicrobial Activity, Pharmacology, Chemistry and Clinical Uses of Oxytetracycline. Internat. Rec. Med. and Gen. Pract. Clin., **168**: 112–131, 1955.
9. Rall, D. P.; Loo, T. L.; Lane, Montague; and Kelly, M. G.: Appearance and Persistence of Fluorescent Material in Tumor Tissue after Tetracycline Administration. J. Nat. Cancer Inst., **19**: 79–85, 1957.
10. Rall, D. P.: Personal communication.
11. Werner, C. A.; Knight, Vernon; and McDermott, Walsh: Absorption and Excretion of Terramycin in Humans: Comparison with Aureomycin and Chloramphenicol. Proc. Soc. Exper. Biol. and Med., **74**: 261–267, 1950.

Prolonged Tourniquet Ischemia of Extremities

An Experimental Study on Dogs * †

BY FRANCIS X. PALETTA, M.D., VALLEE WILLMAN, M.D., AND ARTHUR G. SHIP, M.D.,
ST. LOUIS, MISSOURI

From the Section on Plastic Surgery, Department of Surgery,
St. Louis University School of Medicine, St. Louis

Two hours has been generally accepted as the maximum time that a tourniquet may be left on an extremity with safety during surgical procedures. Bunnell stated that a tourniquet can be safely applied for two hours, and that ". . . after the limb is given a breathing spell of ten minutes, the tourniquet can, if necessary, be reapplied for another hour and a half". Mason and Bell suggested that the tourniquet cuff may remain inflated even longer if it is necessary to complete an initial dissection that includes wound excision and identification of all injured structures. No experimental or clinical evidence has been presented to substantiate this limitation of time for the application of a tourniquet.

Previous studies [1] in our laboratory demonstrated that ischemia for more than four hours in the canine hind limb produced neuromuscular functional impairment and delayed the return of the normal temperature of the skin and muscles of the extremity.

Acting on the hypothesis that these changes might be due to the blockage of small vessels by clots or sludged blood, we designed experiments to test the effect of heparin on the recovery of canine limbs after prolonged tourniquet ischemia. In addition, local hypothermia in the ischemic limb was employed because of its demonstrated beneficial effects on the length of survival of anemic tissues [3].

MATERIAL AND METHODS

Mongrel dogs weighing nine to fifteen kilograms were anesthetized with thiopental sodium, 2.5 per cent, given intravenously. Skin and muscle temperatures in both hind limbs were measured by thermister-needle probes connected to a tele-thermometer. Rectal temperature and room temperature were also continuously monitored. A Kidde pneumatic tourniquet was applied to one thigh and inflated to from 600 to 650 millimeters of mercury after the blood had been expressed from the entire limb with an Esmarch bandage. The tourniquet was left inflated for five hours.

Temperatures were recorded every fifteen minutes during the period of occlusion. After release of the tourniquet, temperatures were recorded every thirty seconds for five minutes, and then every minute for twenty-five minutes. The dogs were observed daily for edema and paralysis of the extremity until complete recovery was apparent.

The animals were divided into four groups. Group I, the control group (seven dogs), was subjected to five hours of tourniquet ischemia of a hind limb without adjuvant therapy. In Group II (ten dogs) the extremity was cooled prior to the application of the tourniquet. Cooling was effected by perfusion with blood at 4 degrees centigrade through the carotid vessels by means of an extracorporeal

* Read at the Annual Meeting of the American Society for Surgery of the Hand, Chicago, Illinois, January 22, 1960.

† This study was supported by United States Public Health Service Grant H 4039 from The National Heart Institute, Bethesda, Maryland.

pump or by packing the extremity in chipped ice. The results with both methods of cooling were similar.

In Group III (eight dogs), a single dose of heparin, 1.5 milligrams per kilogram of body weight, was given intravenously ten minutes prior to the application of the tourniquet. In Group IV (two dogs), a single dose of heparin, 1.5 milligrams per kilogram of body weight, was given systematically ten minutes prior to the release of the tourniquet. Both methods of administration caused prolongation of the clotting time.

RESULTS

After the removal of the tourniquets from the dogs five hours after application, it was noted that the skin and muscle temperatures returned to normal more

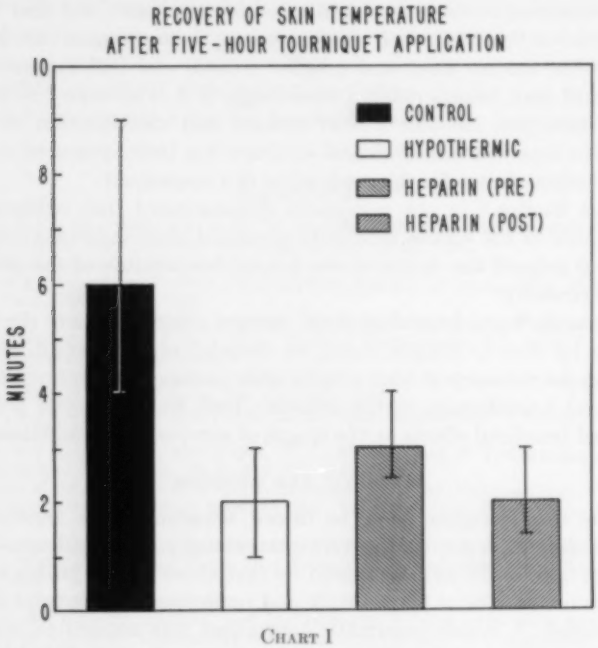


CHART I

rapidly in the limbs of the dogs that had received heparin and in the hypothermic limbs than in the control ischemic limbs. The change in the skin temperature was more striking than that observed in the muscle temperature (Charts I and II).

Application of the tourniquets for five hours to the limbs of the control dogs resulted in the rapid development of massive swelling of the thigh. In the control animals, the circumference of the thigh at the site of the tourniquet increased approximately 25 per cent in ten minutes and 40 per cent in thirty minutes (Table II). The edema gradually resolved over a period of one week. Drop-foot was apparent immediately after recovery from anesthesia; this persisted for approximately two weeks.

Selective hypothermia of the ischemic limb in all the dogs prevented the development of both the edema and the paralysis. The administration of heparin into a normothermic limb by either of the methods used prevented the neuromuscular damage, reduced the degree of edema (Table I), and hastened the resolution of edema.

Stimulation of the sciatic nerve percutaneously above, at, and below the site of application of the tourniquet was carried out with an alternating current of one volt. Stimuli were applied for five milliseconds at one-second intervals. There was no conduction of impulses in the control series of limbs and no response was recorded in the limbs of the animals that had received heparin except when the nerve was stimulated below the site of tourniquet application. Response to electrical stimulation was present at all sites in the hypothermic limbs.

DISCUSSION

Use of the pneumatic tourniquet to produce a bloodless field during operations on the extremities is an accepted clinical practice. Although most surgical pro-

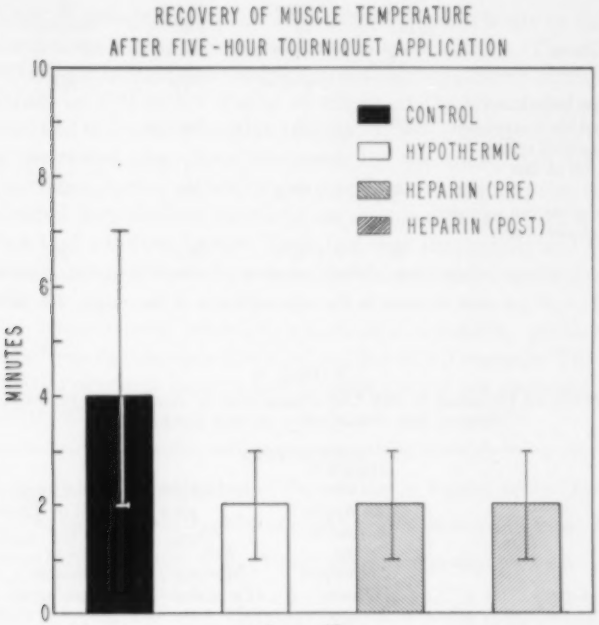


CHART II

cedures can be terminated after a relatively brief period of vascular occlusion, special circumstances may demand prolonged application of a tourniquet. The upper limit of safety for the duration of ischemia in man has never been well defined, although convention has dictated a two-hour period that may be extended briefly, if necessary. It would be useful if a practical means could be developed and documented whereby possible complications might be avoided during unusually prolonged occlusion by a tourniquet.

Preliminary studies reported elsewhere [11] suggested that dogs had good tolerance to ischemia for less than four hours, but that when this period was exceeded, obvious neuromuscular damage occurred, which was associated with delay in the return of normal skin and muscle temperatures. An accompanying phenomenon was the prompt appearance of massive edema at the site where the tourniquet was applied.

The present study has demonstrated that heparin, administered before the application of or before the removal of the tourniquet prevented, in large measure, the neuromuscular damage exhibited as drop-foot, and was associated with a more

prompt return of the temperature of the extremity to normal. The degree of edema formation at the site of the application of the tourniquet was also reduced and resolved more rapidly. The use of the combination of hypothermia and heparin, however, was more effective than heparin alone, as it prevented damage of tissue as measured by the various criteria previously noted. Hypothermia without heparin was also effective.

TABLE I

FIVE-HOUR APPLICATION OF A TOURNIQUET TO THIGHS OF DOGS

Group	No. of Dogs	Edema of Thigh* (*Degree of Increase*)	Drop-foot Present	Persistence of Edema (*Hours*)	Persistence of Drop-foot (*Weeks*)
I; control	7	++++	Yes	168	2
II; hypothermia before the application of the tourniquet	10	0	No	0	0
III; heparin injected before the application of the tourniquet	8	+++	No	24	0
IV; heparin injected ten minutes before the release of the tourniquet	2	+++	No	24	0

* ++++ = 40 per cent increase in the circumference of the thigh; +++ = 25 per cent increase.

TABLE II

PERCENTAGE OF INCREASE IN THE CIRCUMFERENCE OF THE THIGHS OF DOGS AT THE SITE OF THE APPLICATION OF THE TOURNIQUET

Group	Duration of the Application of the Tourniquet (*Hours*)	Increase in Circumference of Thigh after Removal of Tourniquet		
		At Ten Minutes (*Percentage*)	At Thirty Minutes (*Percentage*)	At Twenty-four Hours (*Percentage*)
I-A; control	2	(No change)	(No change)	(No change)
I-B; control	5	25	40	40
II; hypothermia before the application of the tourniquet	5	(No change)	(No change)	(No change)
III; heparin injected before the application of the tourniquet	5	15	25	(None)
IV; heparin injected ten minutes before the release of the tourniquet	5	15	25	(None)

The reason for these beneficial effects is not clear. Some of the bad effects of the prolonged application of a tourniquet in dogs may be due to direct nerve compression, as suggested by various authors[2,6,7,9,10]. Denny-Brown and Brenner demonstrated histological changes in the nerve axon in experimental paralysis induced by a tourniquet in animals. Studies to assess this factor are being conducted.

The beneficial effect of heparin might be explained by its prevention of clotting in the area that was rendered ischemic by the tourniquet. This is a reasonable hypothesis, but it is difficult to see how such a beneficial effect would occur when the administration of heparin was delayed until just before removal of

the tourniquet. Study of a larger series of animals may clarify this confusing observation.

Hypothermia as a protective mechanism has been recommended frequently. Allen, in 1939, suggested the clinical application of hypothermia to plastic procedures on the extremities. Brooks and Duncan, in the following year, stated, ". . . temperature is a powerful factor in determining the length of time tissues rendered completely anemic remain viable". Clinical application of hypothermia in allied fields of surgery is well accepted. Its application to surgery of the extremities may be advocated if these preliminary experimental observations are substantiated by further studies and corroborated in clinical trials.

SUMMARY AND CONCLUSIONS

The effects of the application of a tourniquet for five hours to the hind limbs of anesthetized dogs were studied under various conditions. The time required for the return of skin and muscle temperatures to normal after tourniquet ischemia was determined, as well as the degree of edema at the site of the application of the tourniquet and the neuromuscular damage. Massive edema and drop-foot were observed in untreated dogs after occlusion by the tourniquet for five hours. Heparin administered prior to tourniquet application, or just prior to tourniquet removal, afforded considerable amelioration of this damage, with a lessened degree of edema that resolved earlier. Drop-foot was prevented, and the return of skin and muscle temperatures to normal levels was more rapid if heparin was administered.

Selective hypothermia afforded practically complete protection of the ischemic limbs from the changes observed in the control animals. The explanation of these beneficial effects of heparin and hypothermia is not apparent, and further studies are in progress.

REFERENCES

1. Allen, F. M.: Surgical Consideration of Temperature in Ligated Limbs. Am. J. Surg., **45**: 459–464, 1939.
2. Bastien, J.-B., and Vulpian, A.: Mémoire sur les effets de la compression des nerfs. Gaz. Méd. de Paris, **10**: 794–795, 1855.
3. Brooks, Barney, and Duncan, G. W.: The Effects of Temperature on the Survival of Anemic Tissue. Ann. Surg., **112**: 130–137, 1940.
4. Bunnell, Sterling: Surgery of the Hand. Ed. 3. Philadelphia, J. B. Lippincott Co., 1956.
5. Denny-Brown, D., and Brenner, Charles: Paralysis of Nerve Induced by Direct Pressure and by Tourniquet. Arch. Neurol. and Psychiat., **51**: 1–26, 1944.
6. Eckhoff, N. L.: Tourniquet Paralysis. A Plea for the Extended Use of a Pneumatic Tourniquet. Lancet, **2**: 343–345, 1931.
7. Lewis, T., and Pochin, E. E.: Effects of Asphyxia and Pressure on the Sensory Nerves of Man. Clin. Science, **3**: 141–155, 1938.
8. Mason, M. L., and Bell, J. L.: The Treatment of Open Injuries to the Hand. Surg. Clin. North America, **36**: 1337–1361, 1956.
9. Moldaver, J.: Tourniquet Paralysis Syndrome. A.M.A. Arch. Surg., **68**: 136–144, 1954.
10. Speigel, I. J., and Lewin, Philip: Tourniquet Paralysis. J. Am. Med. Assn., **129**: 432–435, 1945.
11. Walker, J. M.; Paletta, F. X.; and Cooper, Theodore: Relationship of Post-ischemic Histopathological Changes to Muscle and Subcuticular Temperature Patterns in the Canine Extremity. Surg. Forum, **10**: 836–838, 1959.

DISCUSSION

Dr. William L. White, Pittsburgh, Pennsylvania: Dr. Paletta is to be congratulated for his pursuit of a problem that is beset with variation. To have evolved a reproducible state of tourniquet damage with such a crisp manner of control is in itself an achievement of some significance.

In the clinical state, the problem is more varied than in the experimental animal, for here time is not the only factor of importance; we must consider the contour of the bone at the level of tourniquet application, the amount of protective soft tissue, the method of application of the tourniquet, the compressibility of the tissue, the width of the tourniquet, the tension of the uninflated tourniquet, the amount of pressure used, the age and condition of the patient, the nature of the disability and condition of the part, the duration of the disability, and the extent of accidental and surgical trauma. Fortunately, tourniquet palsy is very uncommon.

During recent years I have had more than one battle with the anesthetist concerning the depth of anesthesia when, in the final hour of a long operation, the arm would become engorged, and the wound would suddenly fill with blood. This has occurred even when there has been no change in tourniquet pressure. At first, my fears seemed grounded when I learned that some patients were being paralyzed with anectine rather than anesthetized. We stopped using anectine on all hand cases, but still the late flooding continued. Sometimes, but not always, it is accompanied by a rise in blood pressure. Occasionally, bleeding under a tourniquet appears to be stopped by administration of vitamin K, changing the soda lime, lowering the blood pressure, or giving more anesthetic. Recently, it slowly dawned on me that this bleeding usually occurs when nerves are being repaired just before quitting of the depths of the wound or during skin closure. I am now able to predict this flooding in many instances and believe that painful stimuli must act reflexly or possibly upon the central nervous system despite anesthesia and tourniquet ischemia to produce the bleeding. I now believe that this is not entirely preventable in long operations. The best scheme of prevention seems to be staging procedures and more expedient surgery in the first hour or two.

In a recent incident I predicted this flood of blood in a short and powerfully muscled man with hypogonadism and an old laceration of the ulnar nerve. Despite a stable blood pressure and an unchanged tourniquet pressure, oozing of blood became profuse when the large neuroma was resected and attempts were made to approximate the nerve ends. In desperation, the tourniquet was released when it became obvious that nerve repair was impossible even though the nerve had been previously rerouted through the antecubital space. The amount of bleeding immediately decreased, and a tendon transfer was done without benefit of the tourniquet.

This flooding has almost always occurred in severely injured hands and in those in which there was some major nerve injury and a prolonged period of disability.

I wonder if Dr. Paletta or others have had experiences that parallel mine? If so, then to what is this manifestation of bleeding attributed?

Dr. Paletta has presented to us a most interesting experiment. I feel sure that all of us have had anxious moments about the duration of tourniquet time and welcome the prospect that the use of heparin and hypothermia may eliminate the causes for these anxious moments in the future. We will eagerly await the result of his future clinical studies.

Dr. George V. Webster, Pasadena, California: It was a pleasure to hear Dr. Paletta's presentation of experimental work on the effects of tourniquet ischemia, since this is a major part of our everyday practice in surgery of the hand. The literature has surprisingly few references to factual data in this important field. Opinions and the ever-present voice of experience have been our chief guides to date in estimating proper tourniquet time. We know, however, that if neurons in the brain can last only four to five minutes without oxygen, specialized tissues must have their time limits beyond which damage is irreversible. The objective measurement of temperatures of skin and muscle is an ingenious and seemingly sound method of appraisal of this problem in the experimental animal. The use of heparin as an adjunct is certainly valuable in the study of the experimental problem, but would have limited clinical usefulness owing to possible postoperative hemorrhage despite neutralization of the heparin. Refrigeration of a hand during an operation without general hypothermia would also be difficult. Tourniquet tolerance limits in the animal are not necessarily applicable to the human extremity.

We should turn back to the excellent paper given by our President, Julian Bruner, before this Society in January 1951. Dr. Bruner stated that there was no evidence, clinical or experimental, as to just how long ischemia can be safely prolonged. Unfortunately, this is still true despite this excellent experimental study that is a step in the right direction. Dr. Bruner pointed out that there was great individual variance in tolerance to ischemia. The variables were listed as: (1) age factor, (2) the stiffening factor, (3) the time factor, and (4) the temperature factor. With respect to the latter, he advised the use of a cool irrigating solution for the wound.

An excellent supplementary study on the tourniquet-paralysis syndrome is found in the work of Moldaver. This study showed by conduction times, electrostimulation, and other data that the tourniquet-paralysis syndrome, *per se*, was due to direct mechanical pressure on the nerve, rather than to anoxia to the distal nerve. He described the typical syndrome as consisting in the loss of touch, motor sensation, light pressure, vibration, and position senses. He also noted that there is no appreciable atrophy, since the motor fibers are still in continuity.

In summary, I would like to add only the comment that tourniquet time is precious, the operation should be expedient, and every effort should be made to minimize the hazards incident to the still indefinite proper period of ischemia.

Surgery of the Hand in Cerebral Palsy and the Swan-Neck Deformity*

BY ALFRED B. SWANSON, M.D., GRAND RAPIDS, MICHIGAN

From the Orthopaedic Service, Blodgett Memorial and Mary Free Bed Children's Hospital and Orthopaedic Center, Grand Rapids

Any surgical procedure to improve function of the hand in cerebral palsy must be regarded as a compromise because normal function can never be attained. The disabilities of the hand in this disease often present therapeutic problems that are more complicated than those encountered in traumatic and paralytic deformities. These problems are complex because the functional equilibrium that exists between the intrinsic and extrinsic muscles of the normal hand is often disturbed by muscle spasm or paresis and the associated deformities and contractures that characterize cerebral palsy. Furthermore, the normal functions of contiguous articulations in the fingers and hand are interdependent and any disturbance in one joint will affect other, related joints. In cerebral palsy these interrelated functions are profoundly affected and it may be difficult to determine which deformity is primary and which is secondary.

The majority of deformities of the upper extremity in cerebral palsy are best treated by physical measures such as bracing, stretching, and muscle re-education. In a selected group of cases, certain operative procedures, if done when properly indicated, may assist in the patient's rehabilitation and enable him to perform daily tasks more efficiently because the disabled hand, although not made normal, can now be trained as an efficient assistive member.

The major handicap of the hand in cerebral palsy is the patient's inability to open the hand for grasp. Often, the hand has good strength for closing but does not have efficient extension or the necessary speed of extension, which is so important for normal function. An attempt has been made in this study to analyze the causes of this handicap and to evaluate the results of several surgical procedures performed to correct it.

Approximately 300 children with cerebral palsy have been followed in our clinics, and in approximately five years twelve of these patients have had surgery performed on their hands. This emphasizes the small number of patients with cerebral palsy who are candidates for this type of surgery.

The indications for surgical treatment in the patients included in this study were: (1) sufficient intellectual ability and emotional stability to make rehabilitation feasible; (2) a disabled hand in which function could be improved by osteotomy, arthrodesis, or tendon surgery; and (3) occasionally, a deformed hand in which the appearance could be improved by appropriate bone or tendon surgery in a patient for whom improvement in appearance of the hand was considered to be of definite value.

The contra-indications for surgery were: (1) insufficient trial of physical measures; (2) hand function that could not be expected to be improved by operative treatment; (3) excessive instability of all joints of the hand; (4) lack of voluntary control of the hand muscles; (5) severe sensory disorders; (6) severe

* Read at the Annual Meeting of the American Society for Surgery of the Hand, Chicago, Illinois, January 23, 1959.

athetosis or athetoid shift; (7) inadequate intelligence (intelligence quotient below 70); (8) patient too young (less than seven years of age); and (9) severe emotional disorders.

The most common deformities in the upper extremity in cerebral palsy are: internal rotation of the arm; flexion of the elbow; pronation of the forearm; flexion of the wrist; thumb-in-palm attitude; flexion or extension deformity of the fingers, or both; and instability of the joints associated with spastic, contracted, or paretic muscles.

In this series, surgical treatment as an adjunct to conservative treatment has not been found necessary for deformities of the shoulder and elbow. Pronation deformity of the forearm was treated by: (1) transfer of the flexor carpi ulnaris to the radius or to the extensor carpi radialis brevis or longus; (2) section or transfer of the pronator teres; and (3) osteotomy of the radius.

Flexion Deformity of the Wrist

A flexion deformity of the wrist is the most commonly encountered deformity in spastic paralysis of the upper extremity; it is caused by the predominance of spasm in the flexor muscles of the fingers and wrist. The aim of rehabilitation is to produce good grasp and release and good pinch. This may be accomplished occasionally by establishing muscle balance between the flexors and extensors and thus providing active grasp and pinch, or by tenodesis to supply these functions passively, but frequently these must be supplemented by some form of arthrodesis.

Arthrodesis of the wrist—in the past a commonly accepted operative procedure for this deformity—should be done only after careful evaluation of the function of the extensor muscles of the fingers. In some patients, wrist arthrodesis will help relieve the stretch reflex in the flexors of the fingers sufficiently so that after fusion of the wrist, extension of the fingers can be accomplished. In many patients, however, the extensors of the fingers serve as a tenodesis, with the result that it is the ability to extend and flex the wrist that enables the patient to grasp and release. In these patients arthrodesis of the wrist will often result in loss of ability to extend the fingers. A careful preoperative evaluation of this problem should be carried out by using a brace or a plaster cast to hold the wrist in the desired position.

Tendon transfers around the wrist may serve to balance the forces about the wrist satisfactorily. If transfers are contemplated, their effectiveness should be evaluated before wrist arthrodesis is undertaken. The degree of deformity present before operation and the anticipated balance of muscle power after tendon transfer must be carefully evaluated and the decision made whether to add to extensor power or just to decrease flexor power. This may be accomplished with some success by performing procaine blocks of the wrist flexors as well as by testing muscle power by routine methods. A simple test to evaluate flexion imbalance is to note the degree of wrist flexion needed to enable the patient to extend the fingers completely.

In some of the patients in this study wrist fusion was avoided by the following procedures: (1) transfer of the flexor carpi ulnaris across the dorsum of the forearm to the extensor carpi radialis brevis or longus or to the radius [9] (Cases 8, 9 and 11); and (2) sectioning or lengthening of the wrist flexors (Case 7).

Thumb-in-Palm Deformity

The thumb-in-palm deformity presents a problem not only because it is a poor position for function but also because adduction of the thumb frequently

seems to excite the gripping reflex. This deformity has been treated by tendon transfers designed either to hold the thumb out of the palm actively or to accomplish this end passively by forming a tenodesis. The most frequent tendon transfer has been the flexor carpi radialis to the rerouted extensor pollicis longus (Cases 1, 4, 5, and 9). The metacarpophalangeal joint of the thumb, especially if it is hypermobile, must be fused, usually to prevent the hyperextension of this joint which may result from reinforcement of extensor power. The spastic flexor pollicis longus, the adductor pollicis, and the first dorsal interosseus muscles are primarily responsible for the forces that cause the thumb-in-palm deformity. Occasionally, section of the adductor with stripping of the first dorsal interosseus from the metacarpal of the thumb and lengthening of the flexor pollicis longus tendon are indicated (Case 9). For resistant deformities of this type fusion of the metacarpophalangeal joint, metacarpal bone block, and fusion of the carpometacarpal joint, thus forming a pylon thumb, can be carried out [16] (Case 4). If this procedure is done, temporary internal fixation with a Kirschner wire should be used, and the thumb should be placed so that pinch will be between the thumb and both the index and the long finger. It has been found that flexion of the index finger is often weak, and that the patient will use the long finger for pinch. In this series only one patient (Case 4) required a pylon thumb. Because of its rigidity such a thumb has obvious disadvantages from a functional view point.

Flexion Deformity of the Fingers

Flexion deformities of the fingers may be the result of spasm and myostatic contracture of the flexor muscles [2]. These deformities may best be treated by stretching the contracture and then allowing the wrist to go into flexion in order to open the hand for grasp. However, in resistant cases (Case 2), transfer of the sublimis tendons to the extensors has been done to increase extensor power to balance the remaining flexors. If the sublimis tendons are transferred for this purpose, the proximal interphalangeal joints should be tenodesed in flexion, using the stumps of the sublimis tendons because secondary hyperextension of the proximal interphalangeal joints may follow removal of the sublimis tendons from the fingers and reinforcement of the extensors with the sublimi.

Extension Deformity of the Fingers

The so-called intrinsic-plus or swan-neck deformity of the fingers is common in cerebral palsy due to muscle imbalance and ligamentous and capsular relaxation. This deformity may be functionally disabling and is likely to be decidedly unsightly. To understand the pathogenesis of this deformity it is necessary to be aware of the balances that exist in the normal finger between the flexors and extensors at various levels. At the distal interphalangeal joint, a balance exists between the flexor profundus and the extensor mechanism; here, the extensor mechanism consists of the fused lateral bands that insert into the distal phalanx. At the proximal interphalangeal joint, a balance exists between the flexor sublimis and the middle band of the extensor mechanism; at this level the extensor mechanism consists of the retinaculum and lateral bands, as well as the central slip that inserts into the middle phalanx. At the metacarpophalangeal joint, a balance is maintained between the common extensor muscle and the flexor sublimis and flexor profundus muscles, along with the interossei and lumbricales, which function as flexors of this joint. Predominance of the action of any one of these muscle forces will tend to make the joint involved assume a position of either flexion or extension, depending on which muscle group is the stronger.

The disposition of the entire dorsal apparatus in relation to the transverse

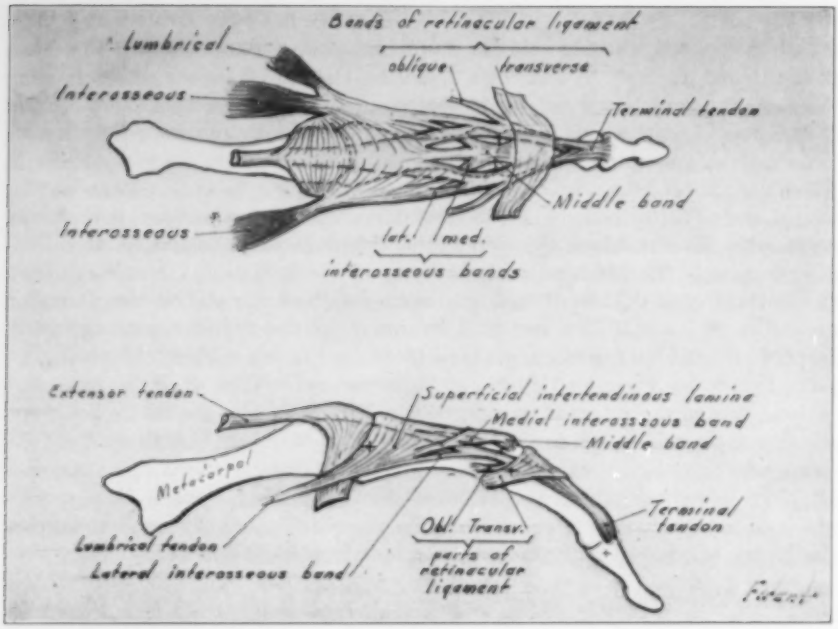


FIG. 1

Drawing (after Landsmeer) shows the relationship of the intrinsic and extrinsic tendons as they fuse to form the dorsal aponeurosis. Both the oblique and the transverse parts of retinacular ligament are attached to the lateral slips, the proximal phalanx, and the flexor sheath at the proximal interphalangeal joint. These attachments prevent the lateral slips from displacing dorsally. Tension on the extensor tendon is transmitted to the middle band without affecting the lateral bands because the distally directed fibers of the intertendinous lamina spread without transmitting any pull to the lateral bands. Tension from the intrinsic muscles, on the other hand, is transmitted to the middle band through the medial interosseous bands. The relative shortness of the middle band, as compared with the lateral bands, may result in the so-called swan-neck deformity. This deformity may be produced by increased tension in either the intrinsic or the extrinsic components. Any dorsal displacement of the lateral bands tends to relax them and to shift the preponderance of force to the middle band. The relative lengthening of the lateral bands increases as hyperextension of the proximal interphalangeal joint occurs. The distal joint then flexes because the tension in the flexor profundus tendon is now relatively greater than that in the relaxed lateral bands due, in part, to the hyperextension of the proximal interphalangeal joint.

axes of rotation of the metacarpophalangeal, distal interphalangeal, and proximal interphalangeal joints plays an important role. The location of axis of rotation at the metacarpophalangeal joint allows flexion to be produced by the intrinsics, whereas at the proximal interphalangeal and distal interphalangeal joints the axes of rotation are anterior to the extensor aponeurosis, a position that enables these muscles to produce extension of these joints.

Two points of attachment of the extensor aponeurosis at the metacarpophalangeal joint and the proximal interphalangeal joint play important roles in the development of the imbalance of the fingers that occurs in cerebral palsy. At the metacarpophalangeal joint there are fibers beneath the aponeurosis that extend from the aponeurosis to the capsule of the joint, to the proximal phalanx, and to the sheath of the flexor tendon. These fibers tend to stabilize the extensor tendon over the central portion of the joint; they also enable this tendon to extend this joint by means of the attachment of these fibers to the joint capsule. Further stabilization of the extensor tendon is accomplished by the insertions of the interossei on the lateral aspects of the proximal phalanx.

At the proximal interphalangeal joint the lateral bands of the extensor mechanism are held toward the palmar side of the finger by the attachments of

the oblique and transverse fibers of the retinacular ligament to the periosteum of the proximal and middle phalanges, the flexor sheath, and the capsule of the joint.

The so-called intrinsic-plus or swan-neck deformity of a finger is caused basically by the relative shortness of the middle band as compared with the lateral bands. This shortening is relative and does not cause limitation of flexion of the proximal interphalangeal joint. The shortening may be due to: (1) fibrosis or spasm of the intrinsic muscles with consequent increased tension on the medial interosseous band which goes to the middle band of the extensor mechanism; (2) overpull of the long extensor tendon on its attachment to the middle band, with consequent increased tension on the middle band, compared with the tension on the lateral bands; (3) rupture of the lateral bands distal to the proximal interphalangeal joint, as occurs in mallet-finger deformity; (4) stretching of the volar capsule and ligaments of the proximal interphalangeal joint with the result that recurvatum of this joint develops—a deformity that allows the middle band to tighten while it relaxes the lateral bands as they displace dorsally; (5) increased strength of the extensors as compared with that of the long flexors, as occurs after tendon transfers to the extensor mechanism; and (6) stretching of the retinacular ligament, which allows the lateral bands to displace dorsally.

A secondary effect of one, or a combination, of the factors just enumerated is imbalance of the muscle forces about the proximal interphalangeal joint in favor of the extensors. The relative lengthening of the lateral bands increases as the proximal interphalangeal joint hyperextends. This lengthening of the lateral bands relaxes the extensor apparatus of the distal joint and the distal joint is then flexed because of the relatively increased tension of the flexor profundus tendon. This tension is enhanced by the hyperextension of the proximal interphalangeal joint.

An attempt has been made to analyze further the mechanical forces that may develop around the joints of the finger (Fig. 2).

The wrist joint and the finger joints form a kinetic chain of which the proximal interphalangeal joint is the weakest link followed, in turn, by the metacarpophalangeal joint. This kinetic chain of joints behaves rather like an accordion door. Thus, if the extensors of the finger are stronger than the flexors, the proximal interphalangeal joint (the weakest link) hyperextends and the contiguous joints flex. When this happens continued muscle force serves to compress the finger in its long axis. As the angles formed at these joints increase, the mechanical advantage of the compression force also increases. As a result, once hyperextension of the proximal interphalangeal joint and flexion of the contiguous joints have developed, these deformities tend to increase. Like an accordion door, the more the door is collapsed the easier it is to collapse it further.

An additional factor is that once the swan-neck deformity has been established, the muscle forces in the finger are so directed that the proximal phalanx tends to be displaced into the palm, with subluxation of the metacarpophalangeal joint (Fig. 2, *2*). In turn, subluxation of this joint tends to aggravate the swan-neck deformity because as the proximal phalanx is displaced volarward with the proximal interphalangeal joint hyperextended, the extensor hood is left behind in a relatively more dorsal position with respect to the proximal phalanx and the two joints proximal and distal to it. As a result, the normal force couple at the metacarpophalangeal joint is disturbed and the spasm of the intrinsic muscles, so common in cerebral palsy, tends to increase both the subluxation of the metacarpophalangeal joint and the hyperextension of the proximal interphalangeal joint. If flexion at the proximal interphalangeal joint can be restored, the muscle forces no longer tend to accentuate the deformity and the normal arch of the finger tends to be restored. Flexion osteotomies of the necks of the metacarpals in severe

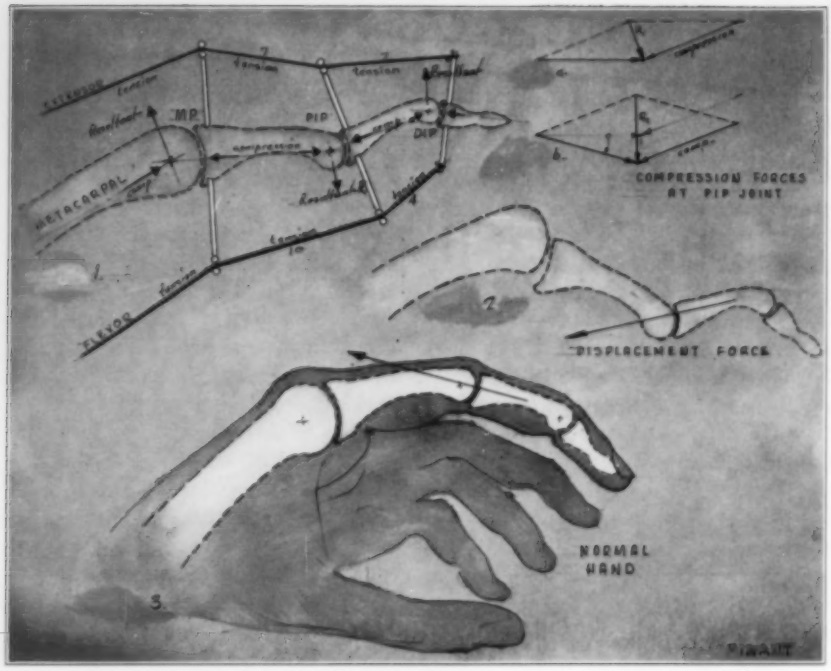


FIG. 2

Section *1* illustrates the compression forces that develop once hyperextension of the proximal interphalangeal joint occurs, and the forces that cause flexion of the contiguous joints. The resultant forces at each joint increase as the angulation increases—the greater the angle at each joint, the greater the deforming force.

Section *2* shows the force that may develop at the metacarpophalangeal joint and cause subluxation.

Section *3* shows that the normal position of slight flexion of the proximal interphalangeal joint directs the compression force at the metacarpophalangeal and proximal interphalangeal joints so that displacement is not produced.

deformities have been used successfully to improve extension of the metacarpophalangeal joints (Case 2). This procedure has worked in cases where relocation of the subluxated extensor tendons over the knuckles has failed (Case 2). It has also been used successfully in the treatment of subluxated metacarpophalangeal joints in rheumatoid arthritis even in the presence of the ligamentous and capsular relaxation and the synovial thickening which accompany this disease.

To analyze further the role of various muscle groups in the production of swan-neck deformity of the fingers in cerebral palsy, selective nerve blocks were performed to eliminate function of the extensor, flexor, and intrinsic muscles, individually or in combination in fourteen patients. The extensor muscles were inactivated by blocking the radial nerve above the elbow. The flexor muscles were inactivated by blocking the median nerve above the elbow. The selectivity of the blocks was determined by noting the paresis and subsequent paralysis of the specific muscle group being studied. The intrinsic muscles of the fingers were inactivated by blocking the median and ulnar nerves at the wrist.

In most of the hands studied by this method it was found that the swan-neck deformity, which appeared as the fingers were extended, was decreased to some extent after the intrinsic muscles were inactivated by nerve block. By contrast, inactivation of the long extensor muscles eliminated the deformity more or less completely, the amount of correction varying with the position of the wrist. As

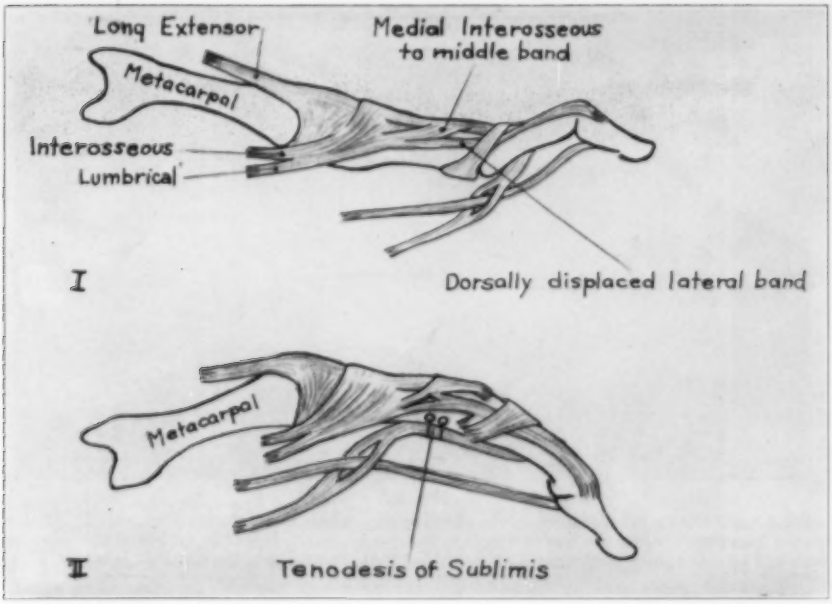


FIG. 3

Section I shows the swan-neck deformity. Note how the long extensor tendon and the medial interosseous band—where it attaches to the middle band—pull on the middle phalanx. Note also the relative relaxation of the displaced lateral bands.

Section II shows a tenodesis of the sublimis tendon with the tendon attached to the proximal phalanx by two sutures passed through two drill holes in the proximal phalanx. The attachment of the sublimis is proximal to the proximal interphalangeal joint, where there is adequate tendon to form the tenodesis without constricting the profundus tendon where it passes through the split in the sublimis. By maintaining the flexed position of the proximal interphalangeal joint the tenodesis re-establishes a more normal relationship between the extrinsic and intrinsic tendons and prevents hyperextension of the joint.

the nerve block took effect and the extensors became weaker, it was noted that the deformity completely disappeared and the patient was able to extend the fingers without hyperextending the proximal interphalangeal joints if the wrist was in neutral position or in dorsiflexion. If the wrist was flexed, however, the swan-neck deformity recurred.

From these observations it would appear that in the so-called intrinsic-plus deformity in cerebral palsy, the deforming force is not produced by the spastic intrinsic muscles alone. The deformity seems rather to be caused by the pull of the spastic intrinsic muscles combined with the chronically flexed position of the wrist. Flexion of the wrist causes the extensor tendons to remain taut and function as a tenodesis. The resulting overpull on the middle band of the extensor mechanism extends the proximal interphalangeal joint and stretches the volar capsule and ligaments. The retinacular ligaments are also stretched, thus allowing the lateral bands to displace dorsally. Hyperextension of the proximal interphalangeal joints then ensues, particularly in the hand with inherently lax ligamentous structures.

Treatment of swan-neck deformity in cerebral palsy should be directed toward the establishment of a normal relationship between the middle and lateral bands of the extensor mechanism and toward the stabilization of the proximal interphalangeal joint to prevent hyperextension. The following methods for accomplishing these purposes have been suggested and used by different authors: (1) lengthening of the intrinsics by stripping the interossei from the

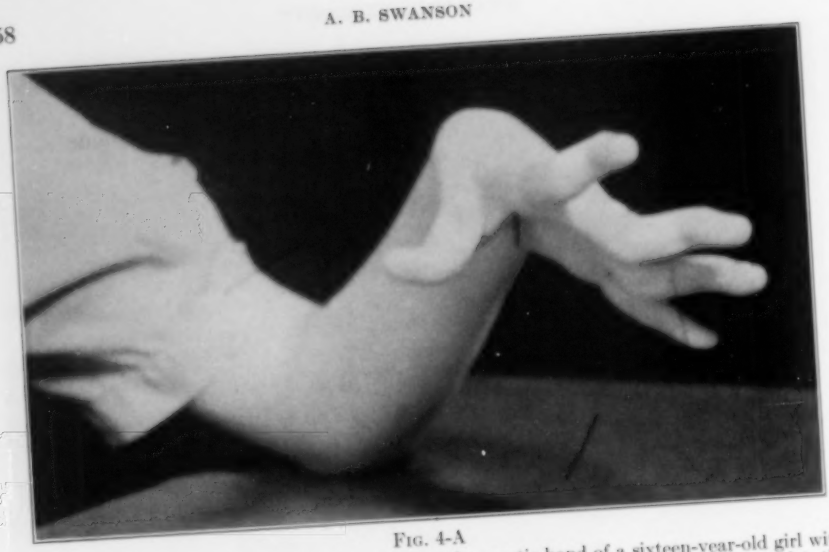


FIG. 4-A

Print made from a preoperative movie, showing the spastic hand of a sixteen-year-old girl with spastic hemiplegia, while she was attempting to open her hand. Note the flexion of the wrist, the flexion of the distal interphalangeal joints, and the hyperextension of the proximal interphalangeal joints.

FIG. 4-B

The same hand three years after tenodeses of the sublimis tendons at the proximal interphalangeal joints of the fingers, transfer of the flexor carpi radialis tendon to the rerouted long extensor of the thumb, and fusion of the metacarpophalangeal joint of the thumb. The patient is now able to open her hand without flexion of the wrist, and there is no hyperextension of the proximal interphalangeal joints, even when the wrist is flexed.

metacarpals [3]; (2) decreasing the pull of the intrinsic muscle on the middle band by cutting the lateral bands or by cutting the component of the hood that connects the intrinsic muscles to the middle band [7,10,12]; (3) shortening of the retinacular ligament to hold the lateral bands in a more volar position [5]; (4) attachment of the long extensor tendon to the proximal phalanx to decrease its pull on the middle band [6]; (5) restriction of hyperextension of the proximal interphalangeal joint by a tendon graft across the volar aspect of the joint [1,4]; (6) fusion of the proximal interphalangeal joint in flexion; and (7) tenodesis of the proximal interphalangeal joint in flexion, using the sublimis tendon, or volar capsulorrhaphy of this joint to limit its extension.

Restriction of extension of the proximal interphalangeal joint by tenodesis has corrected the swan-neck deformity very satisfactorily (Cases 1, 2, 3, 4, 5, and 8). It has also been used with good results for the treatment of this type of deformity when the deformity is the result of trauma, poliomyelitis, or rheumatoid arthritis. This procedure would appear to be more efficient than methods aimed only at the intrinsic mechanism since it corrects the disturbed mechanical forces causing the deformity and re-establishes the dynamic balance between the middle and lateral bands. It has been noted that the lateral bands automatically move volarward when flexion at the proximal interphalangeal joint is maintained.

Prevention of swan-neck deformity depends on maintaining a normal balance between the extrinsic and intrinsic muscle components. In the hand in cerebral palsy, muscle stretching is important, but care should be taken that the braces protect the normal arches of the fingers and hand (Figs. 5 and 6). The ligaments of the joint and the retinacular ligament should not be allowed to become overstretched. In any operation on a finger through a mid-lateral incision, the retinacular ligament should be repaired with care to prevent its healing with excessive length. Correction of joint subluxations at the metacarpophalangeal and proximal interphalangeal joints will be important in certain cases.

SENSORY TESTING

It is important to test the sensation of a hand with cerebral palsy when surgical treatment is contemplated. The functional result of surgical procedures on these hands will depend on sensation as well as on the correction of dynamic and static deformities [14]. In athetosis the hands do not show appreciable sensory loss [18], whereas the spastic hand not infrequently does have a sensory deficit. In cerebral palsy some of the lack of sensory discrimination in the disabled hand is undoubtedly related to lack of sensory experience because the poorly functioning hand has not been used. Most of the sensory deficit, however, is related to structural defects in the central nervous system. The only test of sensation used in the cases reported here was small-object identification. Although this seemed adequate, complete evaluation of sensation including two-point discrimination, stereognosis, and position sense is recommended. A successful operative procedure may improve the balance of the hand but it will not improve useful function if sensation in the hand is inadequate. However, the patient with a sensory defect may be helped by training in the recognition of objects, as well as by functional training.

OPERATIVE PROCEDURE

Tenodesis of the sublimis tendon (Fig. 3), adjusted to hold the proximal interphalangeal joint in approximately 20 to 30 degrees of flexion, was found to be effective and to give lasting results. The patients in this series have been followed up to four years, and there has been no evidence of the tenodesis stretching out and becoming ineffective. This procedure is contra-indicated in the presence of paresis of the flexor profundus muscle. In this situation, the palmar capsule of the joint has been used to fix the joint in flexion (Case 4). In general, it was felt that firmer fixation could be obtained by tenodesis than by capsulorrhaphy.

Tenodesis was performed as follows: Through a mid-lateral incision, the flexor sheath is exposed at the proximal interphalangeal joint and is incised longitudinally to give access to the flexor tendons at this level. The palmar capsule, the palmar plate, the vincula breva, and the periosteum are resected proximally to the proximal interphalangeal joint. The lateral structures are mobilized by subperiosteal dissection and retracted dorsally. Two small drill holes, approximately one-quarter of an inch apart, are made in the neck of the proximal phalanx. These

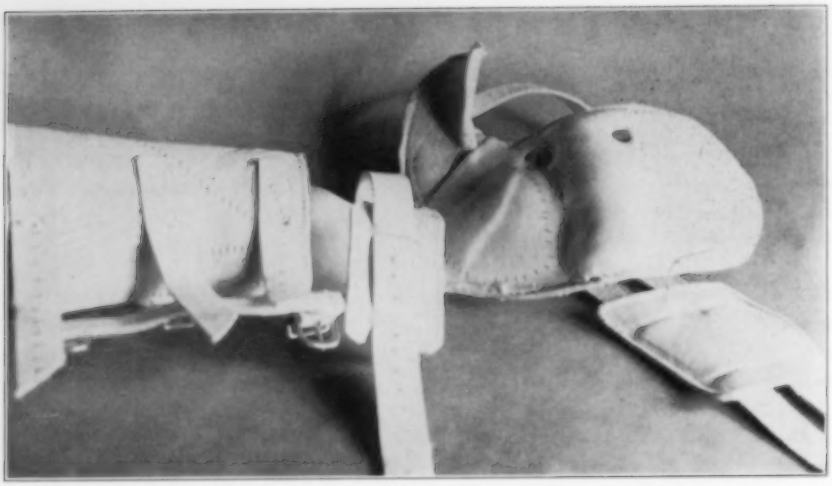


FIG. 5-A

A recommended night splint for a spastic hand is made of shaped aluminum covered with leather. It is built up under the palmar arch and the proximal interphalangeal joints to maintain the normal arches of the hand and fingers. Flexor muscles should not be stretched by hyperextending the finger joints; a flat palmar splint would permit the proximal interphalangeal joints to hyperextend, which may result in hyperextension deformities.

FIG. 5-B

When the splint is applied it maintains flexion of the proximal interphalangeal joints and thus prevents the development of hyperextension deformities. Dorsiflexion of the wrist is accomplished by bending the splint at the wrist. The thumb is held abducted and extended to stretch the intrinsics and long flexor of the thumb.

holes are started on the inferior lateral aspect of the neck of the proximal phalanx and directed obliquely to come out on the palmar aspect of the bone proximal to the articular surface. Dacron or silk sutures are passed through these drill holes to fix the thoroughly scarified sublimis tendon to the bone while the proximal interphalangeal joint is held at 20 to 30 degrees of flexion. The two sutures, one-quarter of an inch apart, hold a broad area of tendon in contact with the denuded bone. The deep structures, including the retinacular ligament, are closed with

plain catgut. A cast is applied to hold the proximal interphalangeal joints in flexion. For this, a long arm cast is used to prevent the cast from moving distally and thus straightening the proximal interphalangeal joints. Small aluminum finger splints have been taped to the fingers to hold the proximal interphalangeal joints in 40 to 50 degrees of flexion inside the cast in some of the later cases. The fingers are immobilized for four weeks. A palmar wrist splint is then used for two more weeks. The patients are warned both preoperatively and postoperatively that the object of the operation is to keep the finger in some flexion; otherwise, they may misunderstand and make an effort to mobilize the finger.

CASE REPORTS

Case 1. S. B., a girl, sixteen years old, with spastic hemiplegia, had a flexed wrist and marked swan-neck deformities of the fingers with locking of the proximal interphalangeal joints in extension. The thumb was clasped, but grasp, release, and pinch were fair. There was sensory object discrimination of a coin, a marble, and a cube. Spasticity was moderate. The patient had undergone a long regimen of physiotherapy and splinting but she carried her hand in her pocket; her motivation to use her hand was poor because it was unattractive and its position did not permit it to function properly. Before operation, the hand was tested with procaine nerve blocks and the wrist and fingers were splinted.

Surgery, performed on March 30, 1956, consisted in tenodesis of the sublimis tendon at the proximal interphalangeal joints of the index, long, and ring fingers; rerouting of the extensor pollicis longus tendon to the flexor carpi radialis tendon; and fusion of the metacarpophalangeal joint of the thumb. Postoperative evaluation showed that there was correction of the intrinsic-plus deformities; the thumb was held out of the palm; the grasp and pinch had improved; and the patient used her hand voluntarily as an assistive hand. There was some impairment in opposition of the thumb; the position of the wrist had improved.

On November 11, 1956, an opponens transplant was performed, with the flexor carpi ulnaris tendon as the pulley. This operation resulted in improved opposition. The patient, whose hand was now more attractive, could hold a telephone, a glass, and small objects. She could type twenty words a minute, using her corrected hand on approximately one-third of the keyboard (October 1958). She was last seen in May 1959; improvement had continued.

Case 2. R. R., a young man twenty years old, had spastic triplegia. His grasp was poor, and there was a tendency of the wrist to go into flexion. The thumb was good, and there was good release. He had had long-term night splinting.

Wrist fusion was performed March 3, 1955, after poor preoperative evaluation. The operation resulted in a stable wrist but decreased extension of the fingers at the metacarpophalangeal joints.

On January 6, 1956, the flexor carpi ulnaris was transferred to the extensor digitorum communis. This resulted in minimum improvement in extension of the metacarpophalangeal joints; there was still lack of extension of the index, long, and ring fingers.

A third operation on January 1, 1957, consisted in transfer of the sublimis tendons of the index, long, and ring fingers to the corresponding extensors; tenodesis of the stumps of the sublimis tendons at the proximal interphalangeal joints; and release of the attachment of the extensor mechanism to the metacarpophalangeal joint capsule. Postoperative examination (March 1957) showed excellent extension of the fingers with improvement in grasp and release of small and large objects. Gradually, there was loss of extension with subluxation of the extensors off the knuckles.

On August 29, 1957, the extensors of the index, long, and ring fingers were rerouted over the knuckles, because of this subluxation, into the interknuckle areas. This procedure resulted in improvement of extension that lasted for four months, at which time the subluxation recurred. The patient was now noted to have a palmar subluxation of the proximal phalanges on the metacarpals. On December 2, 1957, flexion osteotomies of the necks of the index, long, and ring metacarpals were performed to restore more normal relationships of the metacarpophalangeal joints and to decrease the prominence of the knuckles and provide more stable beds for the extensor tendons. Postoperatively, there was marked improvement of extension but some loss of flexion. The patient was pleased with the result. He now has a good assistive hand and works in a woodworking shop, using both hands (June 1960).

Case 3. P. J., a six-year-old girl with spastic quadriplegia, had a clasp tendency of the long and ring fingers of both hands. She could not grasp objects unless she first extended these fingers with the opposite hand. She had good sensation for object discrimination, a good thumb, and good index and little fingers. Spasticity was moderate and coordination fair.

Operation on January 10, 1956, consisted in selective ulnar and median neurectomy to the long flexors of the long and ring fingers of the right hand. Postoperatively, results showed improved grasp, pinch, and release and weakening of the flexors of the long and ring fingers. One year later, tendency toward flexion of the long and ring fingers recurred.

Surgery on the left hand on August 15, 1956, consisted in transfer of the sublimis tendons of the long and ring fingers to the corresponding extensors and tenodeses of the stumps of the sublimi at the proximal interphalangeal joints. Postoperatively, the patient showed good improvement in grasp and pinch and maintained the improved release of clasp. However, there has been some tendency toward flexion of the distal interphalangeal joints. The child has switched handedness to the left because of the relative improvement of her left hand compared with her right (February 1960).

Case 4. A. C., a young woman, twenty years old, with spastic hemiplegia had a flexed wrist, clasped thumb, and hyperextensible proximal interphalangeal joints. Preoperative evaluation showed fair grasp and release; no pulp pinch and no large-object grasp; moderate spasticity; good metacarpophalangeal joint extension with the wrist at neutral; and good sensory object discrimination of a coin, a marble, and a cube. The patient had had long-term bracing.

Wrist fusion was performed on August 14, 1955. A second operation on January 16, 1956, consisted in sublimis tenodesis of the proximal interphalangeal joints of the long and ring fingers; rerouting of the extensor pollicis longus to the abductor position; fusion of the metacarpophalangeal joint of the thumb; and sectioning of the lateral bands of the extensor mechanism of the index finger. Postoperative evaluation of these procedures showed improved grasp, release, and pinch and correction of the swan-neck deformity of the long and ring fingers. The thumb was improved, but there was a continued tendency for the thumb-in-palm position.

A third operation on September 9, 1957, consisted in metacarpal bone block of the thumb with fusion of the carpometacarpal joint of the thumb. This procedure resulted in improved stability and positioning of the thumb. The patient could now pick up pins and coins. There was, however, continued-swan neck deformity of the index finger in addition to a flexion tendency of the distal joint of the thumb.

On January 1, 1958, volar capsulorrhaphy of the proximal interphalangeal joint of the index finger was done. The flexor pollicis longus was lengthened. Postoperative evaluation showed improved stability of the index finger and correction of the persistent hyperextension of the proximal interphalangeal joint of the index finger. The patient now works as a practical nurse; she carries trays, bathes patients, and charts records. She is pleased with the improved function of her hand and with its appearance (September 1959).

Case 5. J. V., a fourteen-year-old girl with spastic hemiplegia had a flexed wrist, swan-neck deformity of the fingers, and a clasped thumb. She had good sensation for the recognition of a coin, a marble, and a cube. Although coordination was good, the position of the wrist and fingers was poor for function, and the patient was sensitive about the appearance of her hand.

Surgery on November 10, 1956, consisted in tenodesis of the proximal interphalangeal joints of the index, long, and ring fingers; transfer of the flexor carpi radialis tendon to the rerouted extensor pollicis longus tendon; and fusion of the metacarpophalangeal joint of the thumb. Postoperative evaluation disclosed correction of the swan-neck deformities; improved extension of the wrist and fingers; and good opposition of the thumb. The patient was able to pick up both small and large objects and was pleased with the function and appearance of her hand. She had some increasing tendency for wrist flexion.

Wrist fusion in neutral position, done on June 6, 1958, resulted in improved wrist stability and some improvement in grasp of heavy, large objects. She was last seen in July 1959.

Case 6. R. C., a thirteen-year-old boy with spastic hemiplegia had a good thumb and fingers but showed a tendency for the wrist to go into flexion and for the forearm to remain in 30 degrees of pronation.

Surgery performed on January 1, 1957, consisted in transfer of the pronator teres through the interosseous membrane to the extensor carpi radialis longus and a rotational osteotomy of the radius to 30 degrees of supination. After operation the patient showed an improved grasp and release mechanism. He could also place his hand in a more functional position. He was last seen in February 1959.

Case 7. I. D., a girl, eighteen years old, with spastic hemiplegia had a flexion tendency at the wrist and impairment of grasp as well as a slight tendency to hyperextension at the proximal interphalangeal joint. She had good coordination and sensation and had had long-term splinting.

On August 16, 1956, the flexor carpi radialis and the flexor carpi ulnaris were lengthened one

inch. Postoperative evaluation showed improved wrist extension with better grasp and release. The patient was able to qualify for a practical-nursing course (October 1958).

CASE 8. R. W., a young woman, nineteen years old, with spastic hemiplegia had a flexion contracture of the wrist; no supination; marked swan-neck deformities of the fingers; and a tendency to lock the proximal interphalangeal joints in hyperextension. The thumb was good and there was gross prehension, but the hand served only as a poor assistive member. The patient had good sensory discrimination of a marble, a cube, and a coin. She had worn a night brace and had had muscle training. Preoperatively, she was tested with procaine blocks and splinting.

On June 7, 1957, the flexor carpi ulnaris was brought across the dorsum of the forearm to the extensor carpi radialis longus and brevis. In addition, a sublimis tenodesis was done of the proximal interphalangeal joints of the index, long, ring, and little fingers. Postoperative examination showed improved functional position of the wrist and fingers, but because position of the index and long fingers was lost in the cast during the postoperative period, on August 10, 1957, tenodeses were again done of the proximal interphalangeal joints of these two fingers. Postoperatively, there was correction of the swan-neck deformity. The patient could pick up small objects like cherries and berries and could fix her hair. Grasp and release were improved, as was the appearance of the hand. The patient could now supinate the forearm to 50 degrees and less shoulder motion was required to place the hands in the positions needed for the performance of different functions. She was last seen in May 1960.

CASE 9. L. D., a sixteen-year-old boy with traumatic spastic hemiplegia, had marked spasm of the flexors, a pronation tendency, poor release, gross grasp, fair coordination, and a clasped thumb. He had sensory discrimination for a marble and a cube. He had had physiotherapy and splinting. Preoperatively, he was tested with procaine blocks and splints.

On August 26, 1957, the flexor carpi ulnaris was brought around the dorsum of the forearm to the extensor carpi radialis brevis and the flexor carpi radialis longus tendon was brought to the rerouted extensor pollicis longus. Additional surgery consisted in arthrodesis of the metacarpophalangeal joint of the thumb and release of the first interosseus and adductor muscles.

Postoperatively, the patient showed improved position of the wrist, improved hand function for assistance in daily activities, and improved grasp and release. He could tie laces, but still had difficulty handling small objects. He was last seen in June 1960.

CASE 10. G. W. a girl, eight years old, had spastic hemiplegia, the result of meningitis during infancy. She had a clasped thumb; a flexed wrist; poor grasp, release, and pinch; and no finger extension. There was fair sensory discrimination of a marble and a cube.

On November 21, 1957, the extensor carpi radialis longus was transferred to the extensor digitorum communis and the flexor carpi radialis longus tendon was transferred to the abductor, extensor brevis, and extensor longus of the thumb.

The operation resulted in a tenodesis effect for extending the fingers and thumb. There was marked improvement in function; the patient used her hand for dressing, eating, and doing schoolwork. She had prehension for the first time. She was last seen in July 1960; improvement had continued.

CASE 11. C. P., a fourteen-year-old girl with spastic hemiplegia had a flexed wrist, a forearm held in pronation, and impaired grasp and pinch. When the fingers were extended the wrist dropped into 30 degrees of flexion. With the wrist held at neutral, there was good control of the fingers and thumb, including active finger extension. The hand could be supinated to neutral.

On December 16, 1957, the flexor carpi ulnaris tendon was transferred across the dorsum of the forearm to the extensor carpi radialis longus and brevis.

At her last postoperative evaluation in May 1960 the active motions were 90 degrees of supination, 80 degrees of pronation, 45 degrees of extension, and 50 degrees of flexion. There was improved grasp and pinch with very little tenodesis action of the finger extensors on grasp and release. The patient could care for her hair and tie her shoes. Use of her hand as an assistive member had increased.

CASE 12. T. F., a boy, sixteen years old, with spastic quadriplegia, had the greatest involvement in the right upper extremity. He had severe wrist flexion, poor grasp and release, and a clasped thumb. The interphalangeal joints were hyperextensible. Sensory discrimination of small objects was poor. There was moderate spasticity.

Operation on September 8, 1958, consisted in wrist fusion in neutral position, except for 15 degrees of ulnar deviation.

Postoperative evaluation showed improved grasp and somewhat less spasticity but no im-

provement in release. The thumb could be moved out of the palm a little better. There was a continued tendency for the development of swan-neck deformities of the fingers, in addition to hyperextension of the metacarpophalangeal joint of the thumb. The patient still needs further surgery.

SUMMARY

There is a small group of patients with cerebral paisy who can be benefited by reconstructive surgery on the upper extremity, in addition to the usual therapeutic measures of splinting and muscle re-education. In cerebral palsy long-standing muscle imbalance, which can be improved only by surgical treatment, may prevent a hand from reaching its full potential for function.

A group of case reports is presented of patients on whom several selective procedures, including arthrodesis, tenodesis, and tendon transfers have been performed. The intrinsic-plus or swan-neck deformity in cerebral palsy is described and illustrated with an analysis of the causative factors involved. It has been observed that the swan-neck deformity is caused by excessive tension on the middle band with relative relaxation of the lateral bands of the extensor mechanism. The tension on the middle band may come from the long extensors or from the intrinsics by way of their connection through the medial interosseous band or a combination of these forces. Prevention of the deformity is stressed and a method of surgical treatment is presented.

REFERENCES

1. Adams, J. P.: Correction of Chronic Dorsal Subluxation of the Proximal Interphalangeal Joint by Means of a Criss-Cross Volar Graft. J. Bone and Joint Surg., **41-A:** 111–115, Jan. 1959.
2. Bechtol, C. O.: Muscle Physiology. *In* Instructional Course Lectures, The American Academy of Orthopaedic Surgeons, 1948. Vol. 5, pp. 181–189. Ann Arbor, J. W. Edwards, 1948.
3. Bunnell, Sterling: Ischaemic Contracture, Local, in the Hand. J. Bone and Joint Surg., **35-A:** 88–101, Jan. 1953.
4. Bunnell, Sterling: Surgery of the Hand. Ed. 3. Philadelphia, J. B. Lippincott Co., 1956.
5. Diaz Humara, José, and Iglesias, Luis: Reconstruction of the Extensor Mechanism of Two Fingers in a Congenital Deformity. A Case Report. Clin. Orthop., **11:** 219–221, 1958.
6. Fowler, S. B.: Personal communication.
7. Goldner, J. L.: Deformities of the Hand Incidental to Pathological Changes of the Extensor and Intrinsic Muscle Mechanisms. J. Bone and Joint Surg., **35-A:** 115–131, Jan. 1953.
8. Goldner, J. L.: Reconstructive Surgery of the Hand in Cerebral Palsy and Spastic Paralysis Resulting from Injury to the Spinal Cord. J. Bone and Joint Surg., **37-A:** 1141–1154, Dec. 1955.
9. Green, W. T.: Tendon Transplantation of the Flexor Carpi Ulnaris for Pronation-Flexion Deformity of the Wrist. Surg., Gynec., and Obstet., **75:** 337–342, 1942.
10. Harris, Crampton, Jr., and Riordan, D. C.: Intrinsic Contracture in the Hand and Its Surgical Treatment. J. Bone and Joint Surg., **36-A:** 10–20, Jan. 1954.
11. Kaplan, E. B.: Functional and Surgical Anatomy of the Hand. Philadelphia, J. B. Lippincott Co., 1953.
12. Landsmeer, J. M. F.: The Anatomy of the Dorsal Aponeurosis of the Human Finger and Its Functional Significance. Anat. Rec., **104:** 31–44, 1949.
13. Littler, J. W.: Tendon Transfers and Arthrodeses in Combined Median and Ulnar Nerve Paralysis. J. Bone and Joint Surg., **31-A:** 225–234, Apr. 1949.
14. Moberg, Erik: Objective Methods for Determining the Functional Value of Sensibility in the Hand. J. Bone and Joint Surg., **40-B:** 454–476, Aug. 1958.
15. Phelps, W. M.: Long-Term Results of Orthopaedic Surgery in Cerebral Palsy. J. Bone and Joint Surg., **39-A:** 53–59, Jan. 1957.
16. Steindler, Arthur: Pathokinetics of Cerebral Palsy. *In* Instructional Course Lectures, The American Academy of Orthopaedic Surgeons, 1952. Vol. 9, pp. 118–129. Ann Arbor, J. W. Edwards, 1952.
17. Sunderland, Sydney: The Actions of the Extensor Digitorum Communis, Interosseous and Lumbrical Muscles. Am. J. Anat., **77:** 189–217, 1945.
18. Tachdjian, M. O., and Minear, W. L.: Sensory Disturbances in the Hands of Children with Cerebral Palsy. J. Bone and Joint Surg., **40-A:** 85–90, Jan. 1958.

Attempted Treatment of Scoliosis by Unilateral Vertebral Epiphyseal Arrest*

BY H. R. McCARROLL, M.D., AND WILLIAM COSTEN, M.D., ST. LOUIS, MISSOURI

From the Department of Surgery (Orthopaedics), Washington University School of Medicine, St. Louis

An attempt has been made to control progressive deformity of the spine resulting from scoliosis in four children by surgical epiphyseal arrest, utilizing an inlay type of bone graft on the convex side of the major thoracic curve combined with the destruction of a portion of the vertebral epiphyseal cartilage adjacent to the graft. The segments selected for this attempted epiphyseal arrest were the three or four vertebrae in a thoracic curve where the convexity of the curve was maximum and the vertebral bodies showed evidence of early lateral wedging. Previously reported experimental work was thought to offer justification for such an approach to the problem of scoliosis, but in each of the four patients in whom an unilateral epiphyseal arrest was attempted, the procedure failed to accomplish the purpose for which it was designed. Studies of the vertebral epiphyseal cartilage removed at the time of surgery in these four patients indicated some basic disturbance in growth that may help to explain the etiology of idiopathic scoliosis.

Haas reported the production of deformity of the spine in young animals by injury to the vertebral epiphyseal cartilages. He pointed out that these observations might prove to have an important bearing on the cause of curvature of the spine and was the first to record the suggestion that in young children this principle might be used as a corrective procedure for deformities of the spine. Bisgard and Musselman independently reported the production of scoliosis in young goats by unilateral excision of the epiphyseal cartilages from vertebral bodies. They showed that the use of onlay bone grafts alone, placed along one side of the spine, produced no alteration in growth of the vertebral bodies unless the epiphyseal cartilages were also disturbed. They, too, suggested that surgery of this type might have some clinical application for the treatment and control of scoliosis. Nachlas and Borden reported the production of scoliosis in young dogs by stapling of the vertebral bodies and subsequent correction of the curvature thus produced by removal of the original staple and the insertion of another staple on the side of convexity (opposite side). LeMesurier, in his discussion of the paper by Nachlas and Borden, reported the surgical destruction of the epiphyseal cartilages on the convex side of curvatures secondary to a hemivertebra in each of four young children, but without the addition of bone grafts. He stated that this idea was suggested by the papers of Haas and Bisgard and Musselman. He reported complete failure of the procedure in all cases. Ponseti and Baird and Ponseti in several subsequent reports showed that the addition of β-aminopropionitrile to the diet of young rats produced changes in epiphyseal structures. Among these changes were alterations in the epiphyseal cartilages of vertebral bodies, with the development of kyphoscoliosis in many instances. This study suggests that primary developmental defects in vertebral epiphyseal cartilages may serve as adequate explanation for the development of idiopathic

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January, 26, 1960.

scoliosis. Microscopic studies of vertebral epiphyseal cartilages of young scoliotic patients, however, have to our knowledge never been reported. Amato and Bombelli, in 1959, also described the disorganization or disorderly arrangement of the cartilage columns in the epiphyseal plates of long bones in experimental animals with lesions caused by aminopropionitrile. Gruca reported the treatment of scoliosis by the insertion of flattened spiral springs under tension along the convex side of the curve, the springs being anchored above and below to ribs or transverse processes. The correction obtained by this method was attributed to correction of existing muscle imbalance and mechanical correction of the curve by the pull of the spring. Is it possible that some of this correction was the result

FIG. 1

Case 1, a child, six years old, with idiopathic scoliosis. The roentgenogram shows mild early scoliosis, with slight lateral wedging of the involved vertebrae at the site of maximum convexity in the thoracic spine.

of unilateral delay or cessation of growth in the cartilage columns caused by the compression force of the spring? If this is true, the change produced by the springs would be comparable to the alteration in growth that followed the stapling of vertebral bodies by Nachlas and Borden.

Roaf reported that multiple wedge resection of interlaminal joints could be combined with partial epiphyseodesis by packing cancellous bone into the spaces between the bodies. He stated that if epiphyseodesis is successful, further growth tends to correct the deformity. One such patient in whom definite improvement had occurred was described in his report.

In addition to the indication that idiopathic scoliosis may result from some basic disturbance in the epiphyseal cartilage of vertebral bodies, many of these reports also suggest that unilateral arrest of growth, by destruction of the epiphyseal cartilages, might represent a reasonable approach to the treatment of certain selected cases. In some young patients with scoliosis very early changes are obvious in the thoracic spine and are characterized by mild unilateral wedging of

the involved vertebral bodies (Fig. 1). In such instances the bodies of the vertebrae that are apparently involved show some decrease in height on the side of the concavity of the curve. In the past, such wedging has usually been attributed to the abnormal pressure forces existing in this area of curvature and, therefore, have been assumed to be the result of the curvature rather than the cause. However, it seems possible that the reverse of this could be true, in which case it would be logical to assume, as others have assumed previously, that it should be possible to control the progression of this asymmetry in growth and simultaneously improve the existing curvature by surgical destruction of the epiphyseal cartilage on the convex side of the vertebrae that show the maximum early changes.

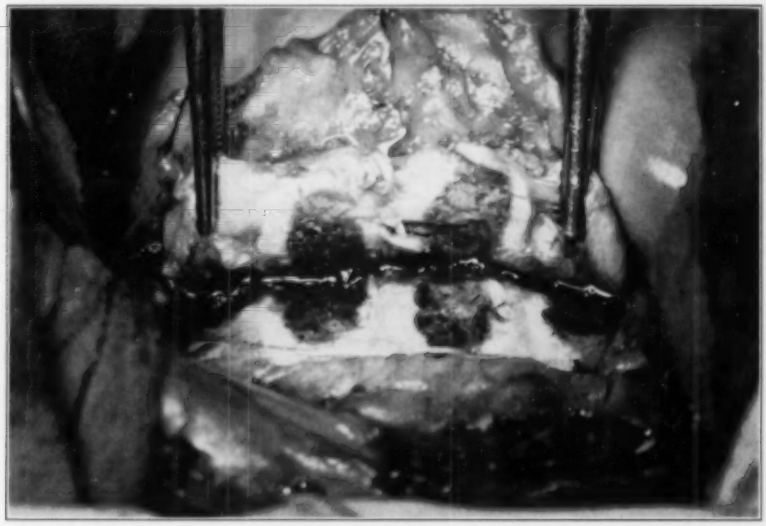


FIG. 2

Lateral view of the thoracic spine with the fascial and periosteal flap elevated, exposing the lateral aspect of the vertebral bodies, the epiphyseal cartilage, and the intervening intervertebral discs.

It was reasoned that a combination of surgical destruction of the epiphyseal cartilages and simultaneous insertion of an inlay type of bone graft, across the localized area of convexity in which early lateral wedging of the vertebrae had occurred, might serve to arrest growth as desired. Hoping to accomplish such correction, four such operations were performed, each in the thoracic area. Of the four, three were for idiopathic scoliosis in children between eight and ten years of age and one was in a child of four years who had scoliosis associated with neuroblastoma arrested by irradiation.

OPERATIVE PROCEDURE

The operations were performed in conjunction with a thoracic surgeon who, in each instance, obtained the exposure over the desired area of the spine. At surgery, one previously selected rib, located at the level of maximum curvature (on the side of convexity), was excised and retained for use as a graft. Since the convex side of the curvature projects laterally into the corresponding portion of the thoracic cage, the exposure represented no major problem. After the desired portion of the spine had been accurately identified roentgenographically after the insertion of a small drill point into one vertebra, a flap of parietal pleura was

first elevated over the lateral surface of the spine, leaving the base of the flap attached anteriorly. After coagulation of the intercostal vessels, a longitudinal incision was then made through the fascia, ligaments, and periosteum along one margin of the vertebrae, with short horizontal incisions at the proximal and distal ends of the longitudinal incision placed so as to outline a flap attached anteriorly or posteriorly. This entire soft-tissue flap was then elevated by sharp dissection from the convex side of the vertebral bodies and the adjacent intervertebral spaces (Fig. 2). With a sharp, half-inch osteotome, a segment of the spine, including bone, epiphyseal cartilage, and intervertebral discs, was removed from the convex side of the spine over the distance desired. The vertebral bodies in a child eight years of age are relatively small, but the width of the segment removed was approximately one-half to three-quarters of an inch (Fig. 3). The depth of the removed wedge varied between one-quarter and three-eighths of an inch, and was sufficient to enter the nucleus pulposus at each exposed interspace. The epiphyseal cartilage in a vertebra of this size is extremely thin, but could be identified in each instance. An attempt was made to further destroy the epiphyseal cartilage extending into the depth of the vertebral body by means of a thin curette. The degree to which this additional destruction of the epiphyseal car-

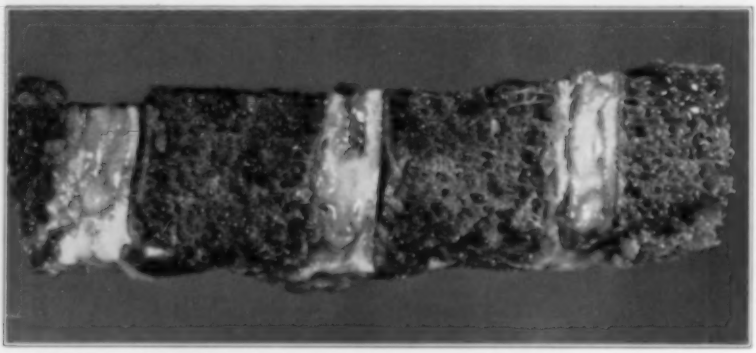


FIG. 3

Segment of the spine including bone, epiphyseal cartilage, and intervertebral discs removed from the lateral aspect of the spine. The thickness of this segment is approximately one-quarter of an inch.

tilage was accomplished could not be determined with accuracy at the time of surgery, but it was thought that approximately one-quarter of an inch of each cartilage was destroyed or damaged about the periphery of the defect. A graft was then prepared from the rib previously excised, cutting it to proper length and removing part of the cortex on its concave surface. The curve of the rib was usually such that it served adequately for an inlay type of graft (Fig. 4). The previously prepared soft-tissue flap was then pulled into position over the lateral aspect of the vertebral bodies and anchored with interrupted sutures of chromic catgut, after which the pleural flap was sutured in place. No immediate postoperative immobilization was used, since it was felt that bedrest and the support afforded by the thoracic cage adjacent to this portion of the spine would suffice. Approximately two weeks after operation each patient was fitted with a snug, high Hoke corset and allowed to be up for increasingly longer periods. Each patient was permitted to leave the hospital after approximately three weeks. No immediate postoperative complications were encountered, and the course in each instance was relatively smooth. After leaving the hospital the patients were followed at regular intervals. Each patient wore the Hoke corset for approximately one year after the operation.

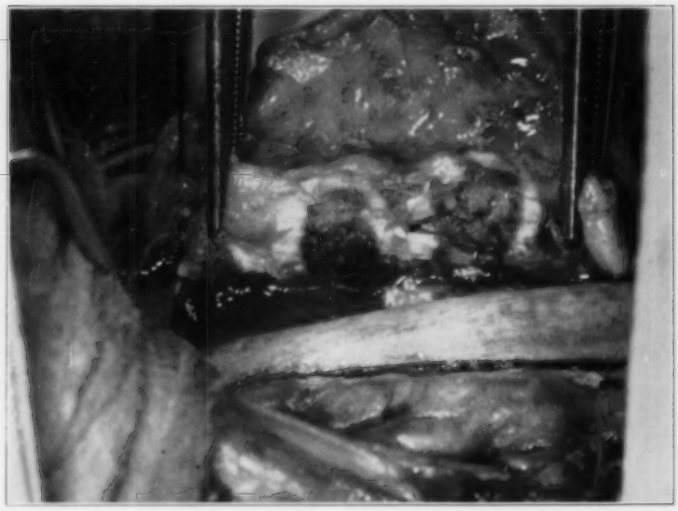


FIG. 4

After removal of the segment of the spine, including bone, epiphyseal cartilage, and intervertebral discs from the lateral aspect of spine over the convexity of the curve and curetting the adjacent portion of each exposed epiphyseal cartilage, the rib graft is laid into the defect. The surface of the graft is approximately flush with the adjacent portion of the vertebral bodies.

FIG. 5

FIG. 6

Fig. 5: Case 1. Immediate postoperative roentgenogram, when the child was ten years old, showing the bone graft inlaid over the convexity of the curvature. Conservative therapy had failed to control progression of the curve (compare with Fig. 1).

Fig. 6: Case 1. Appearance two and one-half years later, showing marked increase in the curvature. Note the pseudarthrosis in the graft over the center interspace.

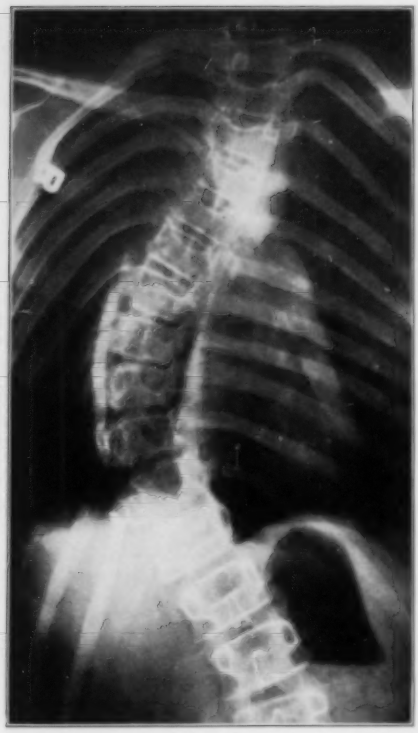


FIG. 7

FIG. 8

Fig. 7: Case 2, nine years of age. Postoperative view of moderately severe idiopathic scoliosis, showing the bone graft inlaid over the convexity of the curve, spanning three interspaces, and the vertebrae showing maximum wedging. The curve had progressed during three years of conservative treatment and measured 45 degrees at this time.

Fig. 8: Case 2. Fourteen months after the attempted growth arrest the curve had increased to 60 degrees opposite the inlay bone graft.

RESULTS

In each patient the placement of the graft was accomplished in accordance with preoperative plans. Roentgenograms in the immediate postoperative period revealed that the graft was in a satisfactory position (Figs. 5, 7, and 11), but, in time, portions of the graft seemed to absorb, and one or more areas of pseudarthrosis developed opposite the intervertebral spaces. It is, of course, possible that arrest of growth in the epiphyseal plates selected for surgery may occur even in the presence of pseudarthrosis, but there was no definite proof that increase in the angulation of the curve was controlled. The segment in which surgery was performed in each patient was very short, and it is difficult to evaluate minor changes in the degree of curve. As far as could be determined, however, each curve showed further progression, and the curve above and below the point of attempted fusion increased in degree (Figs. 6, 8 and 12). Even assuming that local arrest of growth may have been accomplished in some of the vertebrae, it can be stated with certainty that the surgery failed to accomplish the purpose for which it was originally designed.

OBSERVATIONS ON PATHOLOGICAL MATERIAL

The specimen of bone removed in each case at the time of surgery afforded an opportunity to study a portion of vertebral body, the epiphyseal plate, and the intervertebral disc. As far as is known, this represents the only available

FIG. 9

FIG. 10

Fig. 9: Case 2. Appearance two and one-half years later, showing absorption of the bone graft and pseudarthrosis. After the inlay bone graft, the curve increased at the thoracolumbar junction, and, nine months prior to this roentgenogram, partial correction by plaster casts was obtained, and a fusion of the posterior element in this area was performed. There has since been increased angulation at the upper end of the posterior bone graft. The improvement in the angle of the curve opposite the original inlay bone graft was attributed to the subsequent cast correction and fusion of the posterior elements.

Fig. 10: Case 3, a child, one year old, with scoliosis associated with neuroblastoma that had been arrested by roentgen therapy. A mild curve appeared to be developing in the thoracic area opposite the tumor.

study of the epiphyses at the apex of the curvature in scoliotic patients of this age group. The changes were compared with specimens obtained from three other patients of comparable age groups. One of these was obtained from a child who was normal as far as the spine is concerned and died after an accident. The second was obtained from a child eight years of age with a hemivertebra in whom similar surgery was performed, whereas the third was obtained from a child who died of a long-standing chronic disease resulting from congenital fibrocystic disease of the pancreas. The child had extreme growth disturbances and had failed to develop normally in any respect. The comparison of the vertebral epiphyses in these patients with those obtained from the patients with scoliosis has been extremely interesting.

In the normal spine of a child eight or nine years of age, the epiphyseal cartilage consists of relatively uniform columns of cartilage cells, which, for the most part, are smooth and orderly in arrangement (Fig. 13). There are some defects that Beadle described as ossification gaps, and there are some areas in which there exist relatively minor degrees of irregularity in the smooth orderly arrangement of the cell columns. The areas of irregularity and lack of uniformity in the normal spine are relatively rare and represent the exception rather than the rule; this was found to be true in the child with a hemivertebra and in the child who

FIG. 11

FIG. 12

Fig. 11: Case 3. Roentgenogram made when the child was five years old. During a four-year period, the localized thoracic curve had increased to 60 degrees. Six months before this roentgenogram was made a growth arrest was attempted, using an inlay bone graft over the side of the convexity where the lateral wedging of the vertebrae existed.

Fig. 12: Case 3. Roentgenogram made when the child was seven and a half years old. The localized thoracic curve had increased markedly during the period of two and one-half years and now measured 80 degrees.

died after an accident. In the patient who died of congenital fibrocystic disease of the pancreas, however, there was an extreme distortion of this orderly arrangement of cell columns in the epiphyseal cartilage (Fig. 14). It was very difficult to find any area that resembled the orderly arrangement of cell columns present in the normal individual.

In the patients with idiopathic scoliosis this lack of smooth orderly arrangement of cell columns in the growth cartilage was obvious. There were a few isolated areas in each instance in which a relatively orderly arrangement of the columns of cartilage cells seemed to be preserved (Figs. 16 and 18). This, however, was unusual, and for the most part there existed a picture of confusion and disorganization (Figs. 15 and 17). A similar lack of normal architectural pattern was also visible in the cartilage columns of the epiphyseal plates in the child with scoliosis secondary to neuroblastoma (Fig. 19).

It seems likely that the irregularity and lack of uniformity existing in vertebral epiphyseal cartilages may help to explain the deformity that occurs in so-called idiopathic scoliosis. It should also be pointed out that the studies of these patients were made on the convex side of the curve, and no studies of the growth cartilage were available on the concave side, which represents the area of maximum involvement. It seems possible that the changes found on the convex side of the curve may be even more severe on the side of concavity. How much growth potential actually exists on the side of concavity is not known, since no

FIG. 13

The smooth orderly arrangement of the columns of cartilage cells in the normal epiphyseal cartilage of a child, eight years of age, is shown (× 155).

such material was available for inclusion in this study.

DISCUSSION

In this series of cases, the failure of the operative procedure described to accomplish correction or improvement in the deformity in these children may have been influenced by several factors. The destruction of the epiphyseal carti-

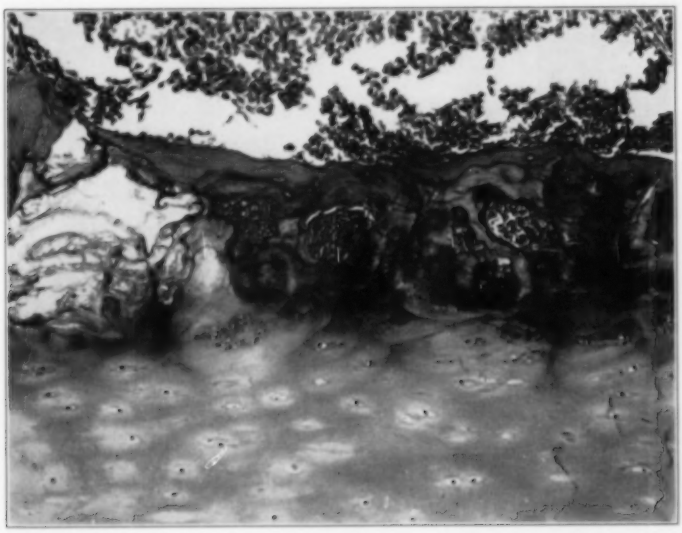


FIG. 14

Epiphyseal cartilage from a child eight years of age who died of congenital fibrocystic disease of the pancreas. Note the total disorganization of the epiphyseal cartilage with loss of the normal columnar arrangement of the cartilage cells (× 155).

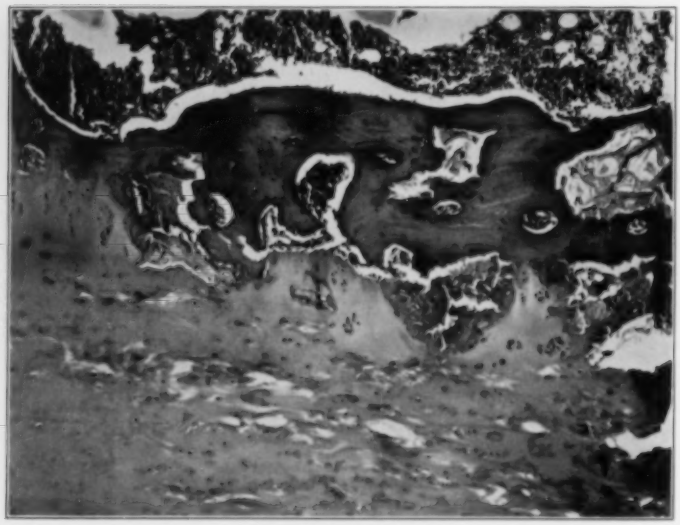


FIG. 15

Case 1, age ten years, idiopathic scoliosis. Epiphyseal cartilage excised from the area of the convexity. Note the loss of the normal columnar arrangement of the cartilage cells in the epiphyseal cartilage and the confused and disorganized replacement, with only a few remnants of the epiphyseal cells visible (× 55).

lage on the side of convexity may have been insufficient to produce growth arrest. Even though satisfactory arrest of growth over the small segment of the curve selected for surgery did occur, this may not have altered the progress of the curve above and below this area. The area selected for growth arrest in each instance included the thoracic vertebrae located at the maximum convexity of the curve, where early lateral wedging of the vertebrae was apparent. It was hoped that growth arrest over this portion of the spine where the greatest lateral

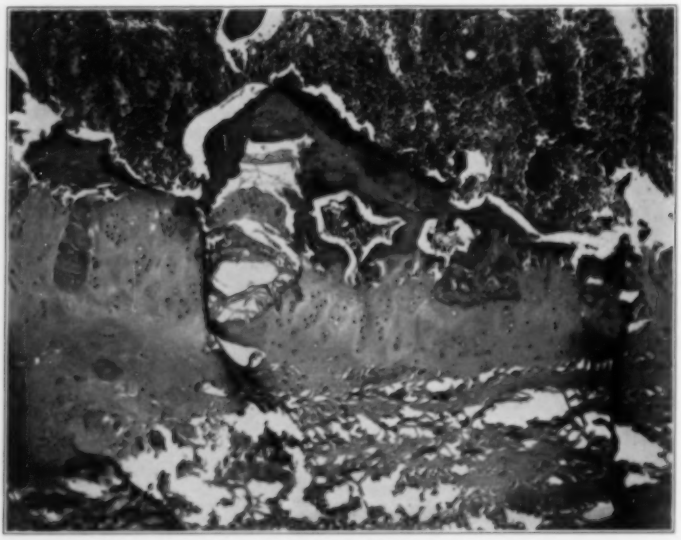


FIG. 16

Case 1. Epiphyseal cartilage showing the only portion of relatively normal arrangement that could be found. There is still loss of the normal columnar arrangement of the cells, and several defects representing ossification gaps, as described by Beadle, can be seen (× 55).

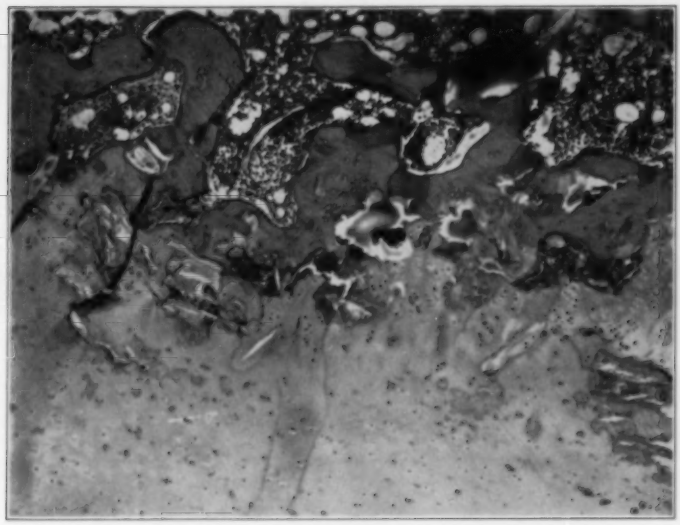


FIG. 17

Specimen from Case 2, a child, nine years old, with idiopathic scoliosis. The epiphyseal cartilage shows total disorganization, loss of the normal columnar arrangement of the cartilage cells, and a picture of utmost confusion (× 55).

wedging had occurred would reverse the development of this supposedly major curve and thereby alter the progression of the other curves above and below this point. It is possible that simultaneous excision of the adjacent interlaminal joints may be essential for the accomplishment of growth arrest and subsequent correction of the deformity. It is also possible that the postoperative immobilization utilized in these patients with the aid of a Hoke corset was inadequate. It should be remembered that if epiphyseodesis on the convex side of the curve is to accom-

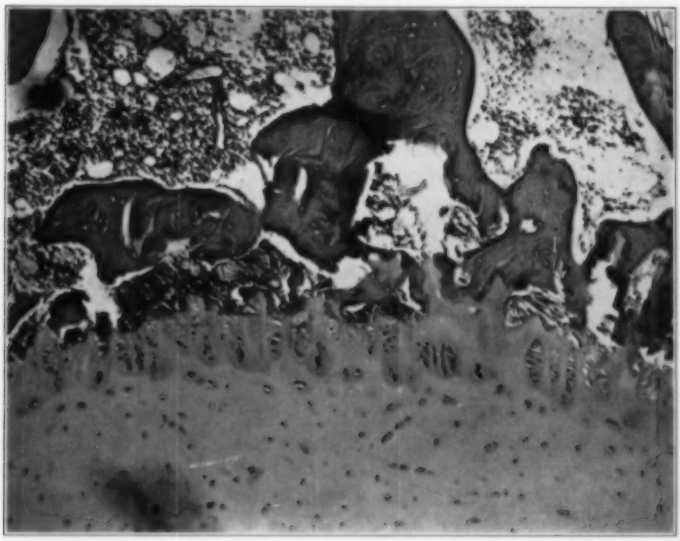


FIG. 18

Case 2. Remnant of epiphyseal cartilage in which there is preservation of the normal columnar arrangement of the cartilage cells. Note, however, the distortion in the cell columns and the lack of smooth orderly arrangement (× 155).

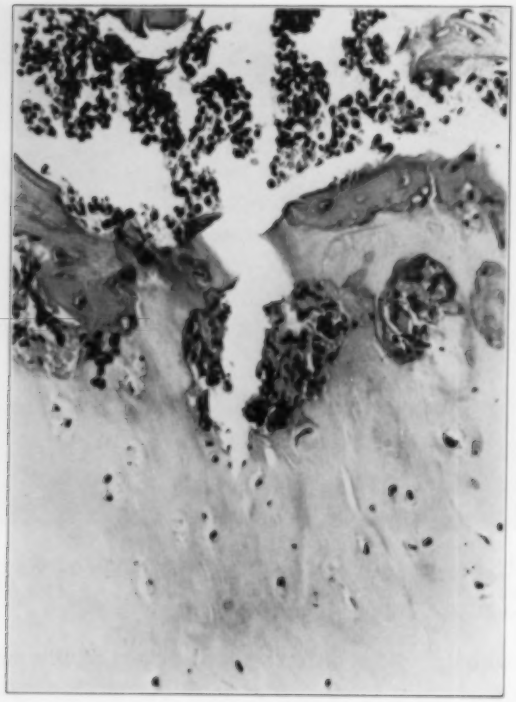


FIG. 19

Case 3, age four years. Epiphyseal cartilage procured when the child was four years old. Note the complete loss of the normal architectural pattern in the cartilage columns (× 155).

plish correction of the deformity, adequate growth potential must exist in the epiphyseal plates on the side of the concavity.

CONCLUSIONS

Obviously, no definite conclusions can be drawn from such a small number of cases. From the standpoint of treatment, it would seem that epiphyseal arrest attempted by means of an inlay bone graft and destruction of the adjacent epiphyseal cartilages of from three to four vertebrae on the convex side of a thoracic curve failed to alter the progress of the local angulation or the progression of the curve above and below this area.

In view of the marked derangement observed in the architectural pattern of the epiphyseal plates in the patients with idiopathic scoliosis, it is possible that this derangement represents a primary growth disturbance that may at least partially explain the deformities associated with idiopathic scoliosis.

SUMMARY

A series of four cases is reported in which an unsuccessful attempt was made to produce surgically a unilateral growth arrest of the vertebral bodies in an isolated area on the convex side of a lateral curvature of the spine. This surgery was performed on from three to four vertebrae at the level of the maximum thoracic curvature where there was evidence of early lateral wedging. The procedure consisted in excision of a block of bone from the side of convexity, further destruction of the adjacent epiphyseal cartilage by means of a curette, and the insertion of an inlay type of autogenous-bone graft taken from a rib on the convex side of

the curve. In three of these patients, the deformity was associated with idiopathic scoliosis. In the fourth, the localized thoracic curvature had occurred in conjunction with an arrested neuroblastoma.

Follow-up study of between two and one-half and three years in each patient indicated that the progression of the curve was not altered. Studies of the epiphyseal plates obtained at the time of surgery indicated that there exists a lack of organization and uniformity in the cartilage-cell columns in patients with scoliosis. These changes may be significant in explaining the etiology of idiopathic scoliosis.

NOTE: Sincere appreciation is expressed to Dr. Thomas H. Burford and Dr. Thomas B. Ferguson of the Department of Thoracic Surgery, Washington University School of Medicine, for invaluable aid in performing the intrathoracic bone grafts.

REFERENCES

1. AMATO, V. P., and BOMBELLI, R.: Early Skeletal and Vascular Changes in Rats Fed on Sweet Pea (Lathyrus odoratus) Seeds. J. Bone and Joint Surg., **41-B:** 600–610, Aug. 1959.
2. BEADLE, O. A.: The Intervertebral Discs. Observations on their Normal and Morbid Anatomy in Relation to Certain Spinal Deformities. Privy Council, Medical Research Council, Special Report Series, No. 161. London, His Majesty's Stationery Office, 1931.
3. BISGARD, J. D., and MUSSELMAN, M. M.: Scoliosis. Its Experimental Production and Growth Correction; Growth and Fusion of Vertebral Bodies. Surg., Gynec., and Obstet., **70:** 1029–1036, 1940.
4. GRUCA, ADAM: The Pathogenesis and Treatment of Idiopathic Scoliosis. A Preliminary Report. J. Bone and Joint Surg., **40-A:** 570–584, June 1958.
5. HAAS, S. L.: Experimental Production of Scoliosis. J. Bone and Joint Surg., **21:** 963–968, Oct. 1939.
6. LEMESURIER, A. B.: Discussion of paper by I. W. Nachlas and J. N. Borden. J. Bone and Joint Surg., **33-A:** 33, Jan. 1951.
7. NACHLAS, I. W., and BORDEN, J. N.: The Cure of Experimental Scoliosis by Directed Growth Control. J. Bone and Joint Surg., **33-A:** 24–34, Jan. 1951.
8. PONSETI, I. V., and BAIRD, W. A.: Scoliosis and Dissecting Aneurysm of the Aorta in Rats Fed with Lathyrus Odoratus Seeds. Am. J. Pathol., **28:** 1059–1077, 1952.
9. ROAF, ROBERT: The Treatment of Resistant Scoliosis. Bull. Hosp. Joint Dis., **19:** 120–151, 1958.

DISCUSSION

DR. I. V. PONSETI, IOWA CITY, IOWA: We are indebted to Dr. McCarroll and Dr. Costen for the first histological study of the vertebral epiphyseal cartilage in children with idiopathic scoliosis. The epiphyseal cartilage was found by the authors to be deranged when compared with that in normal children. The finding of this defect, surmised by us since 1954, is an important contribution to the understanding of the pathology of idiopathic scoliosis. However, the authors lead us to believe that this derangement entails asymmetrical growth of the vertebral bodies, which is presumably the cause of the scoliosis. This assumption appears to be backed by the evidence that scoliosis in experimental animals can result from unilateral injury to the epiphyseal cartilage of several vertebrae. Thus, the authors reasoned that by destruction of half of the vertebral epiphyseal cartilage on the convex side of several vertebrae and fusing this side, the growth of the remaining half of the epiphyseal cartilage on the concave side will correct the deformity in children. This concept, it seems to me, is wrong, and the complete failure of the operation to prevent the progress of the idiopathic scoliosis in all cases appears to prove my point. Idiopathic scoliosis in human patients is not a bending of the spine in the frontal plane due to irregular vertebral growth, but rather is a very complex deformity in which rotation and lateral displacement of the vertebrae and extensive rib-cage distortion are observed. By injuring one side of the epiphyseal cartilage in young experimental animals, only a slight bending of the spine results, with none of the characteristics of the idiopathic scoliosis observed in children. A thoracovertebral deformity similar to the idiopathic scoliosis of human patients can be produced experimentally in young vertebrates with the administration of certain aminonitriles, semicarbazide, or β-mercaptoethylamine. These chemicals produce a defect in the chondroitin sulphate of the ground substance, and the scoliosis is the result of the disruption of the vertebral epiphyseal plates, the loosening of the insertions of ligaments and muscles, and the weakening of the costal cartilages. The epiphyseal-cartilage anomaly demonstrated by the authors in children with idiopathic scoliosis is similar to the lesion observed in the epiphyseal plates of aminonitrile-treated animals. However, this epiphyseal-cartilage lesion in children, important as it is, represents probably only one part of a much more extensive lesion, entailing the weakening of the powerful ligaments of the vertebral syndesmosis, the costal cartilages, and the vertebral and costovertebral articulations. Unless these ligaments

weaken, vertebral rotation and thus true scoliosis probably cannot take place in humans as it cannot in experimental animals.

Another reason to explain failure of the operation is that no effective postoperative immobilization was provided and the portion of the bone grafts bridging the intervertebral disc absorbed and broke. Furthermore, the fusion extended to only three or four vertebrae without in any case extending to the entire curve.

The best available method today to stabilize the spine and prevent vertebral rotation is solid bone fusion of the vertebral arches, including the spinous processes, the laminae, the intervertebral articulations, and the base of the transverse processes and extending through the entire length of the curve. Even this method may fail in severe cases. It appears that intervertebral-body fusion may be a coadjutant but will not replace posterior spine fusion in the treatment of progressive scoliosis.

Eosinophilic Granuloma of Bone

A Study of Twenty-eight Cases

BY MALCOLM H. McGAVRAN, M.D., AND HERBERT A. SPADY, M.D.,
ST. LOUIS, MISSOURI

From the Division of Surgical Pathology and Orthopaedic Surgery, Department of Surgery, Washington University School of Medicine, Barnes Hospital, St. Louis Children's Hospital, and the Barnard Free Skin and Cancer Hospital, St. Louis

During the past thirty-two years twenty-eight cases of lytic lesions of bone with the characteristics of eosinophilic granuloma have been seen in this laboratory. To simply add these cases to the large number already reported would be of little value. However, many of the reports deal with an isolated case [7] or are compilations of previously reported cases [3,7]. Some larger series are reported [6,8,9,14,17] but even in these follow-up data are often absent. It is the purpose of this study to present twenty-eight previously unreported cases with emphasis on the distribution, differential diagnosis, and roentgenographic appearance of these lesions, with particular reference to their course as determined by long-term follow-up.

MATERIAL AND METHODS

The material herein represents twenty-eight consecutive cases taken from a critical review of all inflammatory lesions of bone in the surgical-pathology and clinical files of St. Louis Children's Hospital and Barnes Hospital. This review covered the period from 1927 to the present time. Thus, these cases come from all age groups and represent as unbiased a selection from these hospital populations as was possible. Only those cases in which tissue was available for pathological examination were included; several roentgenographically and clinically suspect, but morphologically undocumented, cases were excluded. Fifteen cases of Hand-Schüller-Christian and Abt-Letterer-Siwe syndromes were biopsied or necropsied during approximately the same period of time.

Histological sections of all the lesions included in this series were reviewed and considered typical of eosinophilic granuloma. Our criteria are the same as those originally described by Lichtenstein and Jaffe, Otani and Ehrlich, and Green and Farber. Differentiation of Hand-Schüller-Christian syndrome and eosinophilic granuloma solely on the basis of microscopic characteristics is difficult, if not impossible. Thus, clinical observations must be considered in establishing the diagnosis. Patients with signs and symptoms of systemic disease—dermatitis, lymphadenopathy, hepatosplenomegaly, anemia, thrombopenia, otitis media, diarrhea, diabetes insipidus, and pulmonic infiltrations, by roentgenogram—when first seen were classified as having Abt-Letterer-Siwe or Hand-Schüller-Christian syndromes. Patients with compatible microscopic bone lesions—either single or multiple—without evidence of systemic or generalized disease at the time they were first seen were classified as having eosinophilic granuloma. Once thus classified, prior to the follow-up study, they were kept in the series regardless of outcome.

In seventeen cases the original roentgenograms were reviewed, and in all cases the roentgenologists' reports were reviewed. Of the fourteen original roentgenograms nine were complete and five were partial skeletal surveys. Twenty-

seven patients were followed to date, December 1959—a maximum of thirty-two and a minimum of three years. The average length of follow-up was nine years. One patient, Case 3, was lost to follow-up. The follow-up study was heterogeneous because of the nomadic habits of the population. Six of the patients were recalled and re-examined; twenty-one were reached by letter or telephone and asked if any further treatment or hospitalization had been required and whether other lesions had developed or deformity resulted. The referring physicians were queried specifically regarding roentgenographic studies.

FINDINGS

Age and Sex

There were fifteen male and thirteen female patients. The average age was 13.3 years. The age distribution is shown in Chart I.

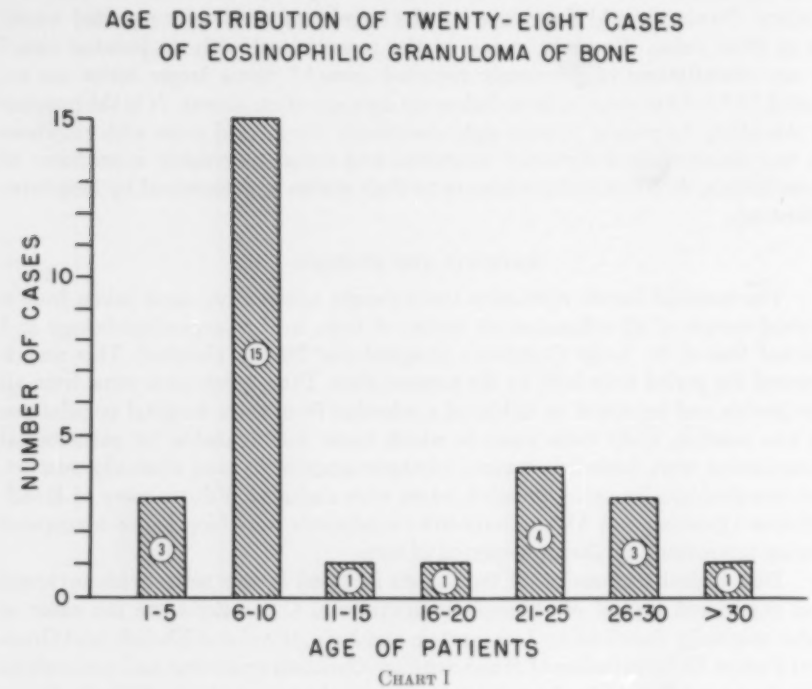


CHART I

Historical, Physical, and Laboratory

Antecedent trauma has been considered by some [12] to be of significance. In only four of the twenty-eight patients reported here was a history of trauma recorded. The dominant symptom was, almost uniformly, pain of short duration. Physical examination sometimes demonstrated a mass, particularly when the lesion involved the skull or ribs. Five patients had minimum elevation of temperature, amounting to from 1 to 2 degrees, Fahrenheit. None of the laboratory examinations was of distinct help in making the diagnosis. Slight leukocytosis with eosinophil counts occasionally as high as 5 to 6 per cent were seen, but this is not uncommon among normal children. Studies of the blood alkaline phosphatase level were done inconsistently and only in one instance was this elevated. The serum calcium levels were within normal range.

Of the nine cases in which bacterial cultures were done only one, Case 21,

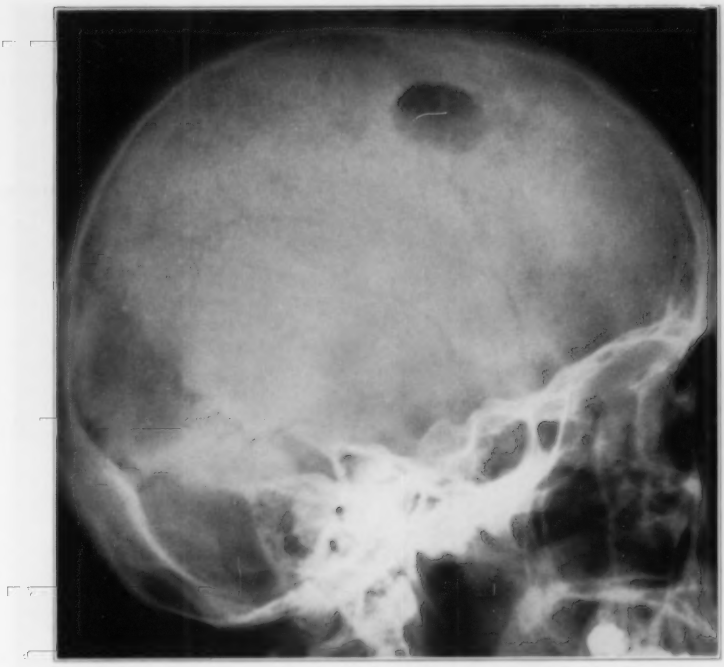


FIG. 1-A

Case 7. Sharply defined defect of the right parietal bone in a white woman, twenty-nine years old, with a history of headaches and a mass. The margin of the defect is not sclerotic and has a fine raggedness. (W.U.Ill. No. 48-4331.)

FIG. 1-B

Anteroposterior view. (W.U.Ill. No. 48-4332.)

FIG. 2-A

Case 22. This seven-year-old girl had eosinophilic granuloma of the ilium. Note the similarity in appearance to the skull lesions in Figs. 1-A and 1-B. Treatment was by curettage. (W.U.Ill. No. 55-5722.)

yielded any information. In this isolated case, tissue from the lesion was injected directly into a guinea pig. Six weeks later the animal was sacrificed and a diffuse granulomatous process infiltrated with eosinophils was found. Acid-fast organisms were identified in the guinea pig's lesions and an atypical acid-fast organism was cultured. Careful re-examination of the sections from this patient failed to demonstrate acid-fast organisms. The cultures from the patient's tissues showed no growth, suggesting the possibility that the inoculum was contaminated or that the animal had a pre-existing infection. In none of the other cases were acid-fast organisms demonstrable in the histological sections. The bacteriological studies, which were usually routine cultures, were sterile.

Roentgenographic

The roentgenographic appearances and diagnoses may justifiably be divided into two groups. Lesions involving the flat bones, usually of the cranial vault, are sharply defined punched-out defects (Figs. 1-A and 1-B). Dermoid cyst and eosinophilic granuloma are the diagnoses usually considered. We did not see the button sequestra described by Wells. Only in later adult life might myeloma be considered, since a well documented case of this disease in childhood is almost unheard of. The lesions of the ilium (Figs. 2-A and 2-B) and mandible are similar to those of the skull.

In the long bones there was no preference for a diaphyseal or metaphyseal location. We did not see eosinophilic granuloma involving the epiphysis. In children (Figs. 3-A through 5-B) both diaphyseal and metaphyseal lesions are destructive processes with erosion of the cortex and moderate to marked periosteal

FIG. 2-B

Roentgenogram made four years later showed a slight residual defect. (W.U.Ill. No. 59-5302.)

new-bone formation. This last change, the onion-peel appearance, has on occasion been thought to be characteristic of Ewing's sarcoma. Expansion of the involved bone, when present, occurred by periosteal layering. The bone defects frequently appeared lobulated with splotchy opacity representing irregular bone destruction rather than intrinsic calcification or ossification. In adults the lesions of the long bones are chiefly diaphyseal and quite different from the lesions in children. The lesions in the long bones of adults are indistinct, centrally placed radiolucencies with very little cortical erosion or periosteal reaction. The rib lesions (Figs. 6-A, 6-B, and 6-C) are lobulated, destructive, and expansile with slight periosteal reaction.

As with many bone lesions the roentgenographic changes give an excellent gross anatomical picture of the process but, unfortunately, they are not diagnostic. We have seen cases of Ewing's sarcoma and osteomyelitis involving the long bones in children in which the roentgenographic findings are indistinguishable from eosinophilic granuloma. Thus, biopsy is imperative for diagnosis.

Therapeutic

The therapy used can be seen in Table II. The skull and rib lesions were usually excised. Other lesions had no treatment, or were curetted or irradiated. Still others had only a biopsy or a combination of the aforementioned therapeutic procedures.

RESULTS

All twenty-eight patients have done well and their lesions have healed. Skeletal surveys were not made routinely on each patient. However, serial roentgenographic surveys of the skeleton were available in nine cases. In none of the

TABLE I

ANATOMICAL DISTRIBUTION IN TWENTY-EIGHT CASES OF EOSINOPHILIC GRANULOMA

Skull	Parietal	4			
	Frontal	2	7	Clavicle	1
	Temporal	1		Scapula	1
Femur			7	Fibula	1
Rib			3	Tibia	1
Mandible			3	Pubis	1
Humerus			2	Ilium	1

twenty-eight patients had there developed, at the time of follow-up, signs or symptoms of sufficient intensity to cause reinvestigation or to arouse the suspicion of the physicians who examined them. The rates of healing of the lesions were quite variable, evidently depending on the age of the patient, the location and size of the lesion, and the amount of bone removed at surgery.

In one patient, Case 12, a moderate varus deformity of the hip was found nine years after curettage and bone-grafting. In another patient, Case 22, a functionally insignificant deformity remained in the ilium four years after extensive curettage. One patient, Case 5, after biopsy of the femur sustained a fracture at the site of the biopsy. The fracture healed satisfactorily. In Case 9, a soft-tissue implant appeared in the area of the scar two years after biopsy and irradiation. This lesion was excised and the area irradiated. The patient has now been followed for thirteen years without showing any signs of recurrence.

FIG. 3-A

Case 25. Eosinophilic granuloma involving the right femoral metaphysis, without cortical penetration or periosteal reaction. This eight-year-old girl had complained of pain, but was afebrile. (W.U.Ill. No. 59-5572.)

Without complete skeletal surveys for each patient at the time of diagnosis and during the period of follow-up, we realize that the assumption that these lesions were solitary is subject to question. Nevertheless, in these patients, if other

FIG. 3-B

Lateral roentgenogram showing extension to the epiphyseal line, but no involvement of the epiphysis itself. The suggestion of radiolucency in the mid-distal portion of the epiphysis is due to the overlying shadow of the acetabulum proximally. (W.U.Ill. No. 59-5573.)

FIG. 3-C

Roentgenogram made two years later shows healing. A few slightly porotic areas remain. This patient had no therapy (W.U.Ill. No. 59-5571.)

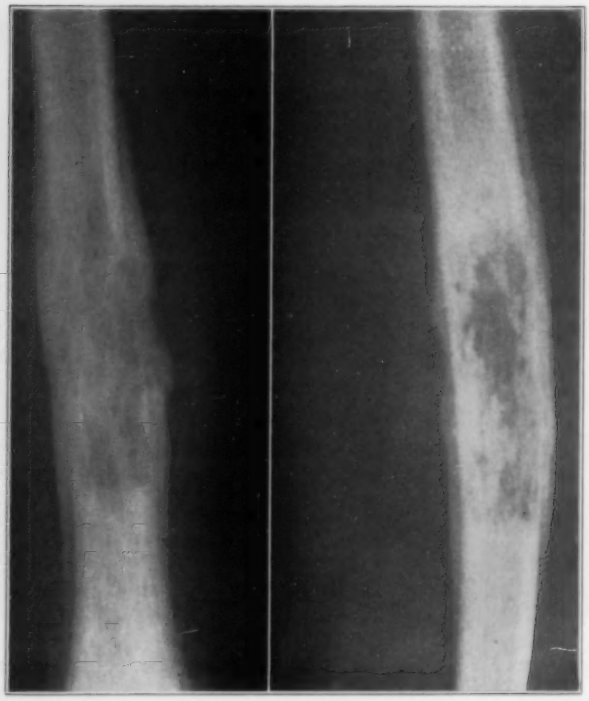


FIG. 4-A

Case 14. This nine-year-old boy had eosinophilic granuloma of the right humerus with extensive cortical destruction and periosteal reaction simulating Ewing's sarcoma or osteosarcoma. The lesion was biopsied and irradiated. (W.U.Ill. No. 51-5164.)

lesions were present at the time of diagnosis or developed subsequently without being visualized in the available roentgenograms, these lesions were and have remained asymptomatic. With the patients, parents, and physicians all aware of the existence of the lesion it would seem likely that even minimum abnormalities would have been promptly investigated. We may, therefore, say that in these patients the lesions were symptomatically solitary.

DISCUSSION

Until the etiology of eosinophilic granuloma is determined debate will continue regarding its pathogenesis and relationships [10,12]. We are not impressed by the present popular concept of reticuloendotheliosis, in which eosinophilic granuloma is considered the localized form and Hand-Schüller-Christian and Abt-Letterer-Siwe syndromes are thought to be the disseminated types. Three reasons for the inclusion of eosinophilic granuloma as the least of the histiocytoses are given:

1. The similar histological changes in the lesions of eosinophilic granuloma and Hand-Schüller-Christian syndrome;

2. The popular concept that transitional forms of reticuloendotheliosis occur through which eosinophilic granuloma changes into Hand-Schüller-Christian syndrome and Hand-Schüller-Christian changes to Abt-Letterer-Siwe syndrome;

3. The natural tendency to consider classification and categorization as ends in and of themselves [10].

That the tissue manifestations are similar is of interest. It is not, however, good evidence to support a theory of common etiology or to confirm an interre-

FIG. 4-B

Seven years later the humerus is of normal appearance, except for slight irregular widening of the medullary canal in the distal one-third. (W.U.Ill. No. 59-5304.)

lationship. Many granulomatous processes—fungal, mycobacterial, and idiopathic—have similar tissue changes.

The transformation of eosinophilic granuloma to Hand-Schüller-Christian disease or to Abt-Letterer-Siwe disease must be, if it does occur, very uncommon. We did not observe this transition in the twenty-eight cases in this study. A critical review of reported cases of transition leaves us skeptical that transitions actually do occur. This is because such patients generally have had incomplete bone surveys initially, or have indications of generalized disease such as dermatitis, anemia, pulmonary infiltrations, and minimum lymphadenopathy that are disregarded while the attention is focused on the one bone lesion [2,4,15]. Otani and others [1,3,6,8,14,17] did not see transitional forms in their case material.

We think that frozen section is a useful and accurate method that can be used in the diagnosis of these lesions. On frozen sections these lesions may be confused with osteomyelitis, but this has not occurred in our experience. If the sections are of poor technical quality they also may be confused with Ewing's sarcoma or reticulum-cell sarcoma. Giemsa smears have proved helpful. With the diagnosis established at the time of biopsy, suitable tissue samples for various studies—morphological and microbiological—can be obtained. This is in contrast to the usual formalin-fixed, microbiologically inert material received in the laboratory. Until meticulous and consistent microbiological studies, including cultures,

TABLE II

EOSINOPHILIC GRANULOMA OF BONE

Case	Age at Onset of Illness (*Years*)	Sex	Symptom	Duration of Symptom (*Weeks*)	Location	Surgery	X-ray Therapy	Original Skeletal Survey	Status at Follow-up	Length of Follow-up (*Years*)
1	6	M	Mass		Right fourth rib, post.	Excision	None	None	Alive, well	32
2	7	F	Mass		Skull, left frontal	Excision	None	None	Alive, well	32
3	6	M	Pain	2	Left fibula	Excision	None	None	(Lost to follow-up)	
4	26	M	Pain		Left tenth rib	Excision	None	Skull	Alive, well	14
5	22	F	Pain		Left femur	Curettage	None	None	Alive, well	14
6	27	M	Pain		Left mandible	Curettage	None	Spine	Alive, well	13
7	29	F	Pain		Skull, right parietal	Excision	1600 r	None	Alive, well	3
8	9	M	Mass	"Many"	Left scapula	Curettage	None	Complete	Alive, well	11
9*	8.5	M	Pain	6	Left femur	Biopsy†	3500 r, original 1800 r, recurrence	Skull, chest	Alive, well	13
10	15	M	Pain		Right femur	Curettage†	2420 r	None	Alive, well	9
11	5	M	Pain		Left femur	Curettage; bone-grafting	None	Pelvis, chest, skull	Alive, well	9
12**	18	F	Pain		Right femur	Curettage; bone-grafting	None	Complete	Alive, well	9

13	9	F	Mass	8	Right sixth rib	Excision†	None	Complete	Alive, well	8
14	9	M	Pain	1	Right humerus	Biopsy†	300 r	None	Alive, well	8
15	25	F	Mass	24	Left clavicle	Excision	None	None	Alive, well	8
16	10	F	Mass	6	Mandible	Curettage	500 r	None	Alive, well	8
17	2	M	Pain	8	Left humerus	Curettage; bone-grafting	600 r	Complete	Alive, well	7
18	7	F	Mass	2	Skull, right temporal	Excision†	None	None	Alive, well	7
19***	1.8	M	Limp	12	Right femur; skull, left parietal	Curettage, femur	None	Complete	Alive, well	6
20	9	M	Pain	6	Right tibia	Biopsy†	None	None	Alive, well	5
21	7.5	M	Mass	6	Skull, left frontal	Excision†	None	Complete	Alive, well	5
22	7	F	Pain	3	Right ilium	Curettage	600 r	Skull	Alive, well	4
23	6	F	Pain	4	Left femur	Curettage†	None	Complete	Alive, well	3.5
24	24	M	Pain	8	Skull, right parietal	Excision†	None	Complete	Alive, well	3
25	8	F	Pain	6	Right femur	Biopsy	None	Unknown	Alive, well	3
26	7	F	Mass	4	Skull, right parietal	Curettage	None	Complete	Alive, well	3
27	41	F	Pain	4	Right mandible	Curettage	None	None	Alive, well	3
28	23	M	Pain	4	Left pubis	Biopsy	1800 r	None	Alive, well	3

* Two years after initial treatment this patient had recurrence, which was treated by excision, in the soft tissue of the scar.
** This patient had a pathological fracture of the femur and now has a varus deformity.
*** The serum alkaline phosphatase level was 22 Bodansky units in this infant.
† Bacteriological studies were done in these cases. All were negative except Case 21 (see text).

FIG. 5-A

FIG. 5-B

Fig. 5-A: Case 9. This boy, eight and a half years old, had complained of pain for six weeks. A roentgenogram showed extensive destruction and periosteal reaction of the left subtrochanteric area, and a tentative diagnosis of Ewing's tumor was made. After biopsy a depth dose of approximately 3500 r was given. Two years later the boy returned with a mass in the soft tissue of the thigh, beneath the scar. This was excised, and histological examination showed eosinophilic granuloma involving the soft tissue. (W.U.Ill. No. 48-6045.)

Fig. 5-B: Roentgenogram made ten years later showed complete healing. (W.U.Ill. No. 58-5095.)

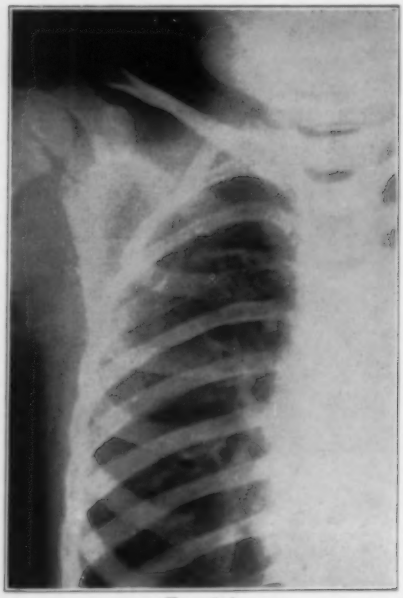


FIG. 6-A

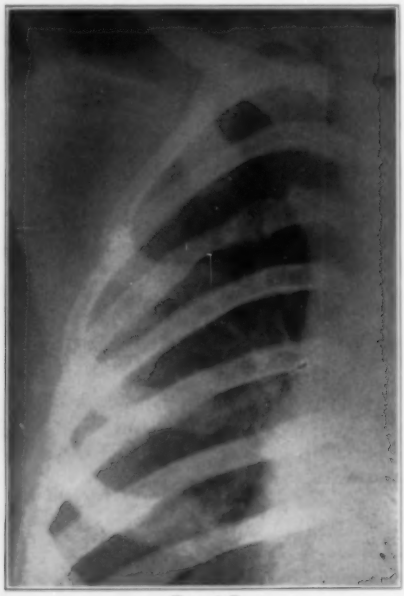


FIG. 6-B

Fig. 6-A: Case 1. A roentgenogram made June 1927 of this six-year-old boy showed lytic, expansile, locular eosinophilic granuloma of the fourth right rib, posteriorly. This lesion was considered on both roentgenographic and pathological examinations to be sarcoma. The segment of rib was excised. (W.U.Ill. No. 53-6917.)

Fig. 6-B: A roentgenogram made four months later showed partial restitution of the excised rib. (W.U.Ill. No. 59-5303.)

animal inoculations, and tissue cultures have been carried out and proved fruitless in a large number of cases, it seems to us that eosinophilic granuloma of bone should not be relegated to the limbo of the histiocytoses. In the past, at our institutions, less than half of the lesions were cultured (Table II). The negative results are not conclusive and unfortunately the isolated case of growth of an atypical acid-fast organism in a guinea pig is only provocative.

We think that after the diagnosis has been established, as just outlined, therapy should consist in conservative removal of the diseased tissue. Where large defects exist bone-grafting or stabilization seems advisable. We have no data from which we can evaluate the relative merits of any single type of therapy.

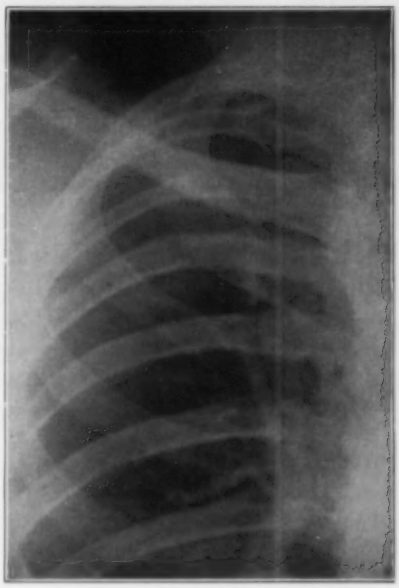


Fig. 6-C

A roentgenogram made twenty-seven years later showed only a slight residual change—a minimum narrowing of the segment of rib. (W.U.Ill. No. 59-5305.)

SUMMARY

1. Twenty-eight cases of eosinophilic granuloma of bone in children and adults, all but one with symptomatically solitary lesions, are reported. The skull, femur, ribs, and mandible were the most frequent sites of involvement.

2. No diagnostic roentgenographic characteristics were found. Lesions of the flat bones were generally punched-out osteolytic lesions. Lesions of long bones were easily confused with malignant tumors. Biopsy is considered imperative to establish the diagnosis.

3. Transition of eosinophilic granuloma to Hand-Schüller-Christian disease or Abt-Letterer-Siwe syndrome has not been encountered in these cases and we have some doubts whether the reported cases of transition represent true changes from one form to another.

4. Therapy has included excision, curettage, small doses of irradiation, or nothing. Evaluation of any one form of treatment is impossible. All the lesions reported in this study healed regardless of the therapy.

5. Meticulous microbiological studies of the tissue from these lesions seem indicated.

REFERENCES

1. Avery, M. E.; McAfee, J. G.; and Guild, H. G.: The Course and Prognosis of Reticuloendotheliosis (Eosinophilic Granuloma, Schüller-Christian and Letterer-Siwe Disease). A Study of Forty Cases. Am. J. Med., **22:** 636–652, 1957.
2. Engelbreth-Holm, J.; Teilum, G.; and Christensen, Erna: Eosinophil Granuloma of Bone—Schüller-Christian's Disease. Acta Med. Scandinavica, **118:** 292–312, 1944.
3. Garsche, Rudolf: Über das eosinophile Granulom des Knochens. Arch. f. Kinderh., **145:** 115–137, 1952.
4. Gillet, P., and Noël, A.: Réticulose de transition. Un cas de granulome éosinophile ayant évolué en maladie de Letterer-Siwe. Acta. Paediat. Belgica, **11:** 213–222, 1957.
5. Green, W. T., and Farber, Sidney: "Eosinophilic or Solitary Granuloma" of Bone. J. Bone and Joint Surg., **24:** 499–526, July 1942.
6. Henderson, E. D.; Dahlin, D. C.; and Bickel, W. H.: Eosinophilic Granuloma of Bone. Proc. Staff Meet. Mayo Clin., **25:** 534–541, 1950.
7. Hill, R. M.: Non-specific (Eosinophilic) Granuloma of Bone. British J. Surg., **37:** 69–76, 1949.

8. HUNTER, T.: Solitary Eosinophilic Granuloma of Bone. J. Bone and Joint Surg., **38-B:** 545–557, May 1956.
9. JAFFE, H. L., and LICHTENSTEIN, LOUIS: Eosinophilic Granuloma of Bone. A Condition Affecting One, Several or Many Bones, But Apparently Limited to the Skeleton, and Representing the Mildest Clinical Expression of the Peculiar Inflammatory Histiocytosis Also Underlying Letterer-Siwe Disease and Schüller-Christian Disease. Arch. Pathol., **37:** 99–118, 1944.
10. LICHTENSTEIN, LOUIS: Histiocytosis. X. Integration of Eosinophilic Granuloma of Bone, "Letterer-Siwe Disease", and "Schüller-Christian Disease" as Related Manifestations of a Single Nosologic Entity. A.M.A. Arch. Pathol., 56: 84–102, 1953.
11. LICHTENSTEIN, LOUIS, and JAFFE, H. L.: Eosinophilic Granuloma of Bone With Report of A Case. Am. J. Pathol., **16:** 595–604, 1940.
12. OTANI, SADAO: A Discussion on Eosinophilic Granuloma of Bone, Letterer-Siwe Disease and Schüller-Christian Disease. J. Mt. Sinai Hosp., **24:** 1079–1092, 1957.
13. OTANI, SADAO, and EHRLICH, J. C.: Solitary Granuloma of Bone Simulating Primary Neoplasm. Am. J. Pathol., **16:** 479–490, 1940.
14. PLATT, J. L., and EISENBERG, R. B.: Eosinophilic Granuloma of Bone. Report of Six Cases. J. Bone and Joint Surg., **30-A:** 761–768, July 1948.
15. SANTELMANN, T., and GIRGENSOHN, H.: Die eosinophile Granulomatose und ihre Beziehungen zur Abt-Letterer-Siwe'schen und Hand-Schüller-Christian'schen Krankheit. Arch. f. Kinderh., **152:** 40–56, 1955.
16. WELLS, P. O.: The Button Sequestrum of Eosinophilic Granuloma of the Skull. Radiology, **67:** 746–747, 1956.
17. WESTLING, PER; SUNDBERG, KURT; and SÖDERBERG, GUNNAR: Systemic Reticuloendothelial Granuloma. Acta. Radiol., Supplementum 149, 1957.

The Pathogenesis of Dupuytren's Contracture

Experimental and Further Clinical Observations*

BY ROBERT D. LARSEN, M.D., NAHOTO TAKAGISHI, M.D., AND JOSEPH L. POSCH, M.D., DETROIT, MICHIGAN

From the Department of Surgery, Wayne State University College of Medicine, the Department of Surgery, City of Detroit Receiving Hospital, and the University Surgical Service of the Grace Hospital, Detroit

In 1833 Dupuytren first described the contracture of the hand that has since borne his name. He believed the affliction to be caused by repeated trauma to the palm. From that time on a great deal was written concerning this disease and the idea that trauma is an etiological factor was either supported or condemned repeatedly.

In 1948 Skoog published an extensive monograph on Dupuytren's contracture. In this monumental work he incorporated a comprehensive description of the pathological changes in this disease, including the nodular hypercellular areas within the aponeurosis. He believed these cellular nodules to be the early stages of the disease. At the margins of these lesions he noted microscopic ruptures of the collagen fibers of the palmar fascia and hemosiderin deposits within the cellular areas. These, he believed, were evidence of previous small hemorrhages. Skoog concluded that Dupuytren's contracture began when microscopic ruptures of the collagen fibers of the fascia occurred.

In 1958 we (Larsen and Posch) reported our interpretation of the abnormal microscopic anatomy observed in sixty-one surgical specimens of Dupuytren's contracture (Series I). We too noted hemosiderin deposits present in the early stages of the contracture. We could not identify any areas that conclusively demonstrated rupture of the collagen fibers. Nevertheless, we felt that the presence of hemosiderin in the early lesions of Dupuytren's contracture was quite important and that this finding made the entire matter worthy of further study.

A method of attacking the problem experimentally was suggested to us by some unpublished work by Pedersen and Gardner of our institution. They scarified the plantar fascia of monkeys, examined it under the microscope, and noted a lesion histologically similar to Dupuytren's contracture.

To determine whether trauma could be an etiological factor in the production of Dupuytren's contracture, we studied additional surgical specimens handled in a special way and also investigated the effects of experimental trauma to the fascia of the hands and feet of monkeys.

CLINICAL INVESTIGATION

Method

Sixty-nine additional surgical specimens of Dupuytren's contracture were examined (Series II). After excision, each specimen was sutured to a piece of stiff white cardboard (Fig. 1) with several sutures placed in both the proximal and the distal ends of the specimen and tied with enough tension to restore and maintain the original length of the specimen during the process of fixation of the tissue. In this manner, curling, kinking, and overlapping of the tissues during the process of fixation were prevented. The areas where the contracture had

* Read at the Annual Meeting of the American Society for Surgery of the Hand, Chicago, Illinois, January 23, 1959.

seemed to be most pronounced on gross inspection were noted on an outline tracing of the entire specimen. After fixation, the specimens were removed from their cardboard backing. Long segments of the diseased portions of the fascia were cut from the whole specimen. These segments were then embedded in paraffin, sectioned in the sagittal plane (Fig. 2), and stained.

By preparing the tissues in this manner, we obtained long uninterrupted sections of fibrous tissue both proximal and distal to the nodules of hypercellular connective tissue. We thought such sections would enable us to determine whether the fibrous tissue in the regions of the cellular areas had been ruptured. In addition,

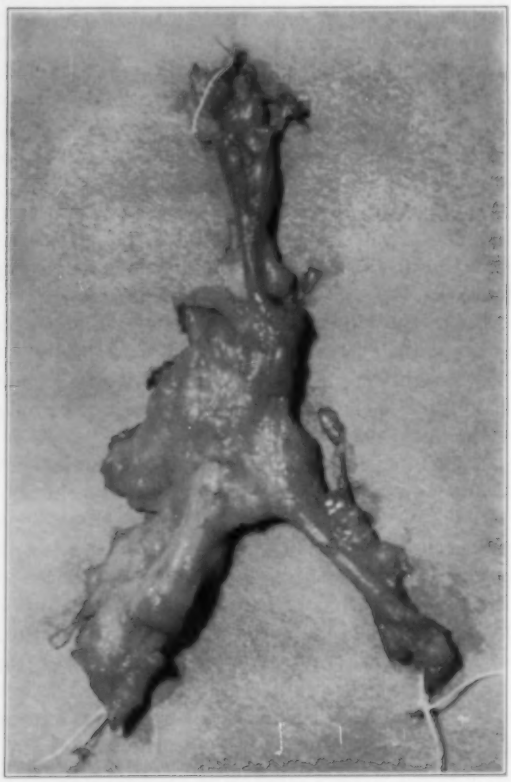


FIG. 1

Technique of mounting the entire surgical specimen on stiff cardboard before fixation in 10 per cent neutral formalin.

multiple sections through the cellular areas were studied in an effort to determine if a more complete histological study of these areas would show a higher incidence of hemosiderin deposit than we found in the specimens of Series I.

The tissue in this study was fixed with 10 per cent formalin buffered to pH7 with monosodium and disodium phosphate and stained with hematoxylin and eosin, Mallory's and Masson's connective-tissue stains, Verhoeff's elastic-tissue stain, and with toluidine blue to demonstrate metachromasia. Bennhold's Congo red method to demonstrate amyloid was also used[7].

Findings

The contracted bands in the fascia were observed to be made up of relatively hypocellular collagenous tissue (Fig. 3). The cell nuclei in these areas were stained

very intensely; little or no nuclear detail was visible. The nuclei were fifteen to twenty times longer than they were broad and were widely separated by collagen fibers. These fibers stained intensely reddish orange with eosin. Some of the very dense areas had a reddish blue color in the hematoxylin and eosin preparations.

The cellular areas contained numerous immature nuclei of fibroblasts (Figs. 4 and 5). Some of these nuclei were round, but most were elliptical, their length being only about twice their breadth. A nucleolus and many fine granular strands

FIG. 2

A slide prepared by the method described in the text.

FIG. 3

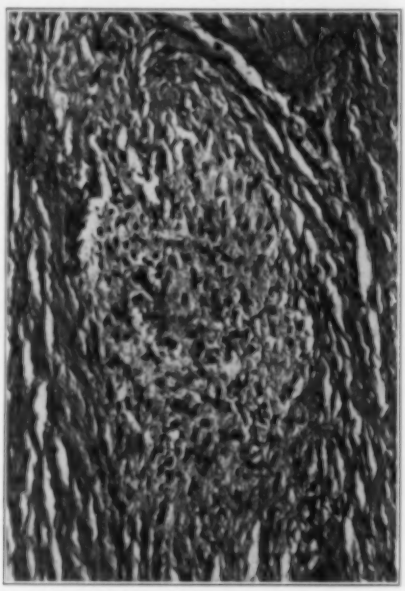


FIG. 4

Fig. 3: Photomicrograph of a dense contracted band of collagen tissue characteristic of the late or lamellar stage of Dupuytren's contracture (hematoxylin and eosin, ×135).

Fig. 4: Photomicrograph of a nodule of proliferating fibrous tissue characteristic of the proliferative phase of Dupuytren's contracture (hematoxylin and eosin, ×180).

were visible within each nucleus. The cellular margins in these areas were indistinct, and interspersed between the nuclei was a haphazard network of many fine fibers. The finest of these fibers stained a light lavender in hematoxylin and eosin preparations, whereas the slightly larger ones had a pale orange color.

The cellular areas were more or less nodular in shape but were not encapsulated. The fine fibers within these nodules could be seen to blend insensibly into the bundles of more mature collagenous tissue at the margins of the nodules. The dense mature collagen bands and the quite immature fibrous tissue of the nodules appeared to represent the two extremes of the disease between which

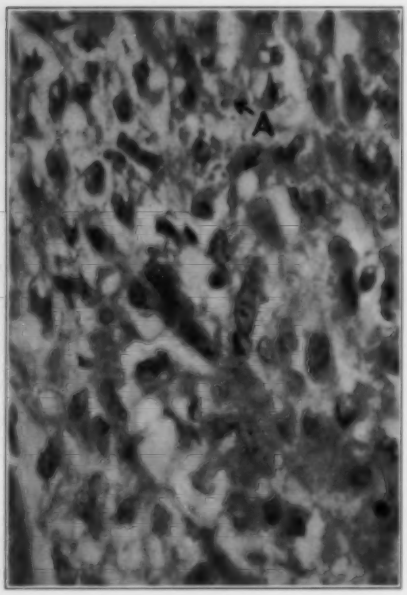


FIG. 5

FIG. 6

Fig. 5: Photomicrograph shows the detail of the cellular and fibrous structure of the nodule shown in Fig. 4 (hematoxylin and eosin ×600). The granules marked *A* are hemosiderin granules; note their small size at this magnification.

Fig. 6: Intermediate stage of Dupuytren's contracture. The fibers are thicker and the nuclei are more elongated than in Fig. 4 and are oriented in a single direction (hematoxylin and eosin, ×600).

there were numerous intermediate stages (Fig. 6). The plump nuclei of the immature nodules tended to elongate as the collagenous fibers became thicker. At the same time the nuclei stained more intensely and became more widely separated by the collagen fibers, which stained orange or red-orange with eosin. As the tissues matured these fibers were more numerous and appeared to be thicker. Finally, the mature contracted scarlike stage was reached.

Masson's connective-tissue stain showed that the fine fiber network in the hypercellular nodules was made up of collagen fibers. The finest fibers did not take the green stain, but the fibers that were slightly larger than the very finest did. Verhoeff's elastic-tissue stain failed to demonstrate proliferation of new elastic tissue in these lesions.

Sections stained with toluidine blue showed metachromatic staining in the areas of proliferating tissue. Metachromatic staining was not present in the normal aponeurosis, nor did this reaction occur in the mature bands of the contracture. In the more advanced cellular stages of the contracture occasional areas of very pale pink metachromatic staining were noted. Bennhold's Congo red method failed to demonstrate amyloid in any areas of the normal palmar aponeurosis or in any stage of the contracture.

In the sixty-one specimens in Series I we were able to demonstrate iron pigment within the cellular nodules nine times. In the hematoxylin and eosin preparations, the iron pigment appeared as golden yellow or yellow-brown granules that stained blue with the Prussian-blue reaction. We looked carefully for hemosiderin in all sixty-nine specimens of palmar fascia in Series II; over 500 different areas were removed from the sixty-nine specimens for study, and serial sections made of several of the areas. In twenty-four of the sixty-nine specimens, only mature

FIG. 7

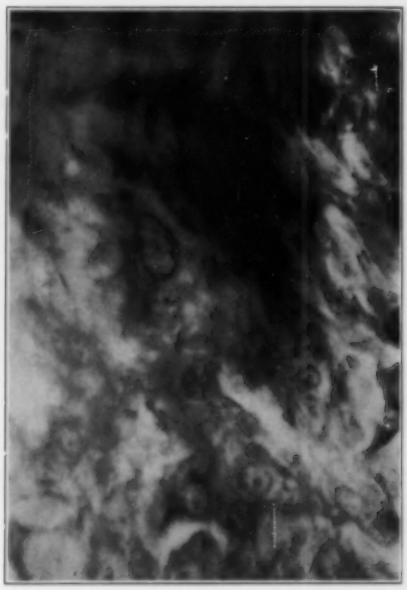


FIG. 8

Fig. 7: Edge of a proliferating nodule of fibrous tissue showing abrupt termination of collagen fibers. The area opposite the arrow is shown in greater detail in Fig. 8 (Mallory's connective-tissue stain, ×180).

Fig. 8: The area opposite the arrow in Fig. 7, ×1100 (Mallory's connective-tissue stain).

contracted bands were found; however, the remaining forty-five specimens contained actively proliferating fibrous tissue in one or more areas. Nineteen of the forty-five contractures (42 per cent) that contained actively proliferating tissue had hemosiderin within the proliferating areas. Hemosiderin was found only in the most cellular stages of Dupuytren's contracture (Fig. 5); it was not found in the more advanced stages, nor was it found in the normal aponeurosis.

Skoog published photomicrographs illustrating the areas which he believed showed rupture of the aponeurosis. Tissues handled in the same manner as those in Series II provided long sections that were cut parallel to the long axis of the contracted bands. In our Series II we found many areas which closely resembled Skoog's illustrations (Figs. 7 and 8). In these areas the fibers of the aponeurosis were observed to end abruptly at the edge of an area of cellular proliferation. Other fibers lying adjacent to the interrupted fibers continued through the areas of proliferation uninterrupted. The fibers that appeared to have been interrupted had a more sinuous appearance than the fibers that did not appear to have been interrupted.

Serial sections were made of the areas in which we observed abrupt termination of collagen fibers. These demonstrated that the fibers did not continue uninterrupted in the next section. For example, the abruptly-terminating fibers shown in Figures 7 and 8 did not continue on into the sections superficial or deep to this section. The appearance of these abruptly ending fibers seemed to be produced by the actual termination of the fibers.

When it was found that interruption of collagen fibers could be demonstrated in the tissues of Series II, we reviewed the sections of Series I but found no evidence of interruption of the fibers. It appears, therefore, that the sections must be cut parallel to the longitudinal fibers of the aponeurosis in order to demonstrate interruption of the fibers.

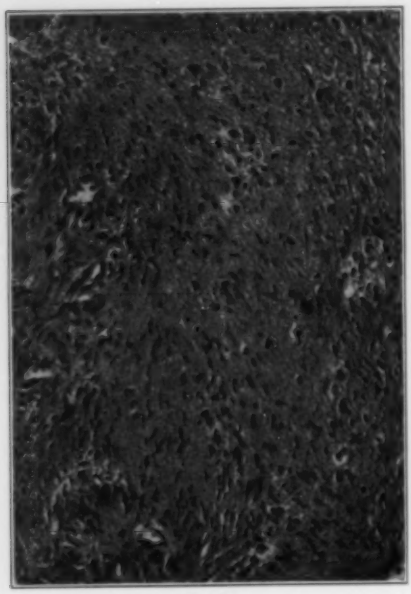


FIG. 9

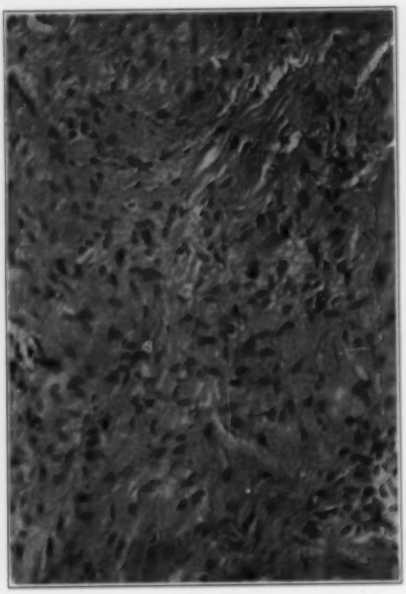


FIG. 10

Fig. 9: Section of a nodule of proliferating fibrous tissue removed from the patient described in Case 1 (hematoxylin and eosin, ×180).

Fig. 10: Section through the nodule of proliferating fibrous tissue removed from a monkey's palmar fascia three months after partial rupture of the fascia. Note the abrupt termination of the mature fibers (hematoxylin and eosin, ×180).

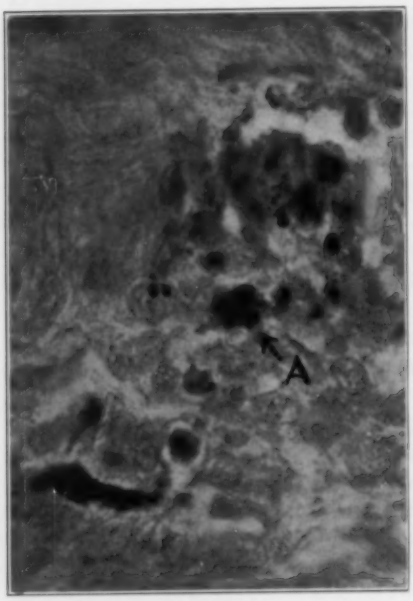


FIG. 11

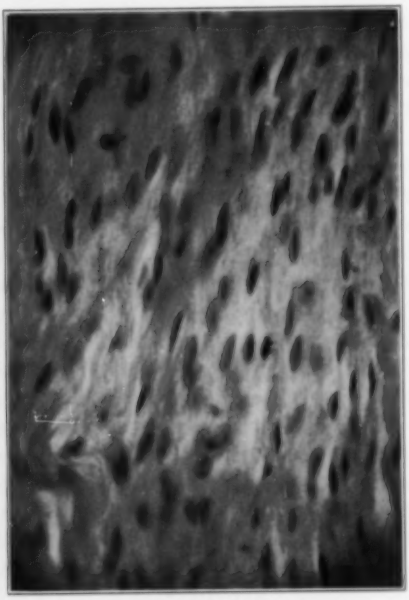


FIG. 12

Fig. 11: Section through the nodular lesion in the monkey palmar fascia (Prussian-blue stain, eosin counterstain, ×800). The dark areas at *A* are hemosiderin and are blue in this section. This lesion was one month old when excised.

Fig. 12: Lesion of a monkey's palmar fascia excised five months after partial rupture of the fascia (hematoxylin and eosin, ×400).

The specimens from Series II provided no additional information with regard to the relationship of the cellular stages of the disease to the increase in capillary vascularity in the cellular regions. The same observations were made repeatedly by numerous authors in the past [5]. There is an increase in capillary vascularity in the region of the proliferating tissue and at times the wall of a capillary vessel seems to blend insensibly with the proliferating fibrous tissue. In these areas the fibrous tissue appears to arise directly from the wall of these small vessels. As the mature contracted stage of the disease is reached, the vascularity of the tissue is markedly reduced.

CASE 1. We encountered one human lesion, apparently the result of trauma, that had great similarity to Dupuytren's contracture. A white boy, seventeen years old, had sustained a small laceration of the palm on a piece of glass eight months before coming to us. The flexor tendons of the ring finger were lacerated at the level of the distal palmar crease. The digital sensory nerves were not involved and the wound had healed primarily. A nodular mass, one centimeter in diameter, developed beneath the skin scar. The nodule, which had not been present prior to injury, was slightly painful at times but was not tender. At the time of tendon repair, no foreign body could be found in the palm and the nodular area was found to lie within the palmar fascia. The nodule was excised and on microscopic examination was found to consist of proliferating fibrous tissue with plump, oval nuclei enmeshed in a network of fine connective-tissue fibers (Fig. 9). Small areas of the lesion contained golden brown pigment granules that stained positively for iron with the Prussian-blue reaction. Histologically, this lesion could not be distinguished from one of the proliferating nodules of a Dupuytren's contracture. Interestingly enough, at the time of his first visit and before he was operated on, this patient was observed to have the knuckle-pads often found in Dupuytren's contracture.

EXPERIMENTAL RUPTURE OF THE PALMAR AND PLANTAR FASCIA IN MONKEYS

Method

All four extremities of three Cebus and nine rhesus monkeys were operated on. None of the monkeys had any evidence of any disease or deformity of the hands or feet. Intravenous sodium pentobarbital anesthesia was used and in each extremity a bloodless field was obtained by an Esmarch bandage. Sterile surgical technique was used throughout. An incision was made in the proximal end of the palm or sole and the skin and subcutaneous tissue were elevated as gently as possible from the superficial surface of the palmar or plantar fascia. A strip of fascia about three to four millimeters wide and two and a half centimeters long was then elevated from the interstitial tissues, which adhere to its deep surface, leaving the ends of the fascial strip attached. (In the foot, a muscle arises from the deep surface of the plantar fascia and the strip of plantar fascia was dissected away from this muscle.) Two sterile dural silver clips were then clamped on the strip of fascia, leaving a segment of fascia about one and a half centimeters long between the clips. The strip of fascia outside the clips (proximal and distal to them) was then grasped with hemostats. The hemostats were gently pulled apart until partial tearing of the fibers of the fascia lying between the clips could be detected (the band of fascia was not completely ruptured, except in one instance in which the entire band suddenly gave way). The fascia was then laid back in its bed in the hand or foot and the tourniquet was removed. Bleeding was controlled by compression until clotting occurred, and the skin was closed with interrupted nylon or cotton sutures. A piece of gauze moistened in collodion was made to adhere to each wound. Each animal was given 300,000 units of penicillin intramuscularly and returned to its individual cage where it remained throughout the postoperative period. All the monkeys removed their own skin sutures with their teeth; usually, all sutures were out by the end of the first week. One of the forty-eight wounds became infected; the remainder healed by primary intention.

Each animal served as its own control as follows. In one extremity the fascia was partially ruptured between the dural clips just described. In a second extremity of the same animal partial rupture of the fascia was accomplished, but the clips were not used. In the third extremity the strip of fascia was elevated as described but was not ruptured; it was simply placed back in position and the wound was closed. In the fourth extremity the fascial strip was elevated and clips were applied, but the strip was not ruptured; it was returned to its bed and the wound was closed.

In this manner there were two extremities in each animal with a strip of fascia that had been partially ruptured, one with and one without clips. We also had two unruptured fascial strips, one with and one without clips.

The hands and feet of each monkey were operated on a second time from one to nine months after the original operation. The portion of fascia lying between the clips was excised from each of the four extremities. Two monkeys were reoperated on at one month, two at two months, two at three months, and one each at four, five, six, seven, eight, and nine months. The excised fascia was fixed in formalin, embedded in paraffin, and sectioned and stained in a manner similar to the method employed in Series II.

Gross Findings

When the skin of the hand or foot was opened a nodular lesion was lying within the palmar or plantar fascia. In the partially ruptured areas, which were identified by dural clips, the lesion was noted to lie between the clips. In the partially ruptured fascia in which clips were not used, the nodular lesion was still easily identified. The presence or absence of the clips made no grossly recognizable difference.

In the control extremities in which the fascial strips were elevated but not ruptured, only diffuse thickening of the fascia was found without nodularity. There was no grossly recognizable difference between the unruptured strips of fascia that had and did not have the clips.

During the first two or three months the nodular lesions were soft and reddish gray. After six to nine months the nodular shape was less marked, although still present. In these older lesions, the nodules were firmer in consistency and of a yellow-gray color which more closely resembled the color of the surrounding normal aponeurosis.

Microscopic Findings

In the lesions excised at one, two, and three months (Fig. 10) there was proliferation of fibrous tissue in the area of rupture. The ruptured mature fibers could be traced to the margin of the proliferating area where they ended rather abruptly. There was rather marked capillary vascularity associated with the proliferating fibrous tissue. The nuclei of the fibroblasts in the proliferating areas were round or oval and contained an easily visible nucleolus and finely granular material. The cellular margins were indistinct in these areas and the intercellular fibers stained poorly with eosin. The finest fibers did not stain at all with eosin but had a pale lavender color.

Scattered among the nuclei in the proliferating areas, there were golden yellow or yellow-brown granular deposits of hemosiderin (Fig. 11) that stained blue with the Prussian-blue stain. Masson's trichrome stain indicated that the fibrous network in the proliferating area was collagen. The finest fibers in the network did not take the green color of the Masson stain. Verhoeff's elastic-tissue stain indicated that there was no formation of new elastic tissue here.

FIG. 13

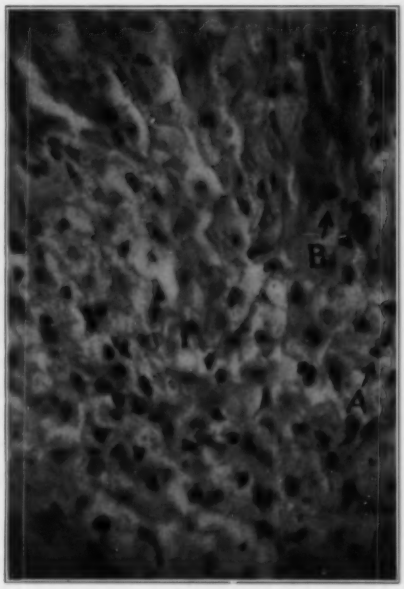


FIG. 14

Fig. 13: Lesion of a monkey's palmar fascia excised nine months after partial rupture of the fascia (hematoxylin and eosin, ×180).

Fig. 14: Section through a nodule in the rectus sheath of a dog taken one month after partial rupture of the sheath. The granule at *A* is hemosiderin; note at *B* the abrupt termination of the mature collagen fibers (hematoxylin and eosin, ×400).

Metachromatic staining of the proliferating areas was noted in toluidine-blue preparations.

In the older lesions, which were excised from the fourth to the ninth month after rupture, there was progressive maturation of the proliferating fibrous tissue (Fig. 12). The nuclei were oval and increasingly oriented with their long axes in the same direction. The collagen fibers became progressively thicker, losing their haphazard arrangement and becoming organized into a more regular lamellar pattern. By the ninth month the lesion resembled a mature scar (Fig. 13). The vascularity decreased progressively in the older lesions. The amount of iron pigment also decreased progressively. At the end of nine months only a very few granules of hemosiderin could be found.

In the control specimens the lesions that had been produced by partial rupture of the aponeurosis without the use of the identifying dural clips were histologically identical to the lesions in which the clips were used. The dural clips remained inert in this experiment, as far as we could determine.

Pedersen and Gardner found that scarification of the plantar fascia caused a fibrous-tissue proliferation that resembled Dupuytren's contracture. We found that the elevation of the fascial strip produced a diffuse thickening of the fascia. On microscopic examination the surfaces of the fascia showed proliferating immature fibrous tissue similar to that in the ruptured fascial strips. The reaction, however, was less intense and subsided more rapidly than did the lesion produced by rupture of the fascia. At nine months the unruptured strip of fascia was a thin regular structure which closely resembled the normal fascia. No nodular lesions were observed in the strips of fascia that were not ruptured. It would seem, therefore, that the fibrous-tissue proliferation is a response of the palmar or plantar fascia to trauma, whether the trauma be rupture of the fibers or simple

elevation of a strip of the fascia. The reaction is more intense and lasts longer when the fibers are actually ruptured.

In none of the monkeys did a contracture develop and all digits retained full extension. No functional loss could be detected by observing the animals in their cages.

EXPERIMENTAL RUPTURE OF THE ANTERIOR RECTUS SHEATH OF A DOG

Six similar operations were performed on the anterior rectus sheath of a dog. The resulting lesions were excised at intervals of one to five months.

The amount of cellular hyperplasia in these lesions seemed to be much less than in the monkeys' palmar and plantar fascia and the lesions healed rapidly. After one month the ruptured area was filled with numerous immature fibroblasts enmeshed in a network of fine connective-tissue fibers (Fig. 14). Iron pigment granules scattered between the nuclei of the immature fibroblasts stained positively with the iron stain (Prussian blue). The specimen removed two months after rupture of the sheath showed very few of these cellular areas. The specimen taken at the end of three months showed complete healing.

DISCUSSION

Much has been written regarding the etiology of Dupuytren's contracture. Almost all the authors concerned themselves with the statistical relationship between the contracture and various occupations or associated disease. The articles that concern the role of trauma in the causation of Dupuytren's contracture are also, for the most part, statistical studies that compare the incidence of this disease in manual laborers with that in persons with more sedentary occupations. The conclusions drawn are about equally balanced for and against trauma as a cause of Dupuytren's contracture. We doubt that a conclusive answer can be obtained from this type of study.

Skoog was the first to describe the abrupt termination of collagen fibers at the margins of the cellular areas of Dupuytren's contracture. He interpreted this finding as a partial or microrupture of the fibers. He also observed that the ruptured fibers had a wavy appearance, as if tension on these fibers had been released. Our observations confirm those of Skoog.

Lagier and Rutishauser, however, believed that the fibers are not ruptured; they stated that it is the wavy course of the fibers that causes them to pass out of the plane of the section. Thus, the fibers appear to terminate but actually pass on uninterruptedly into the next section. Our serial sections do not support this conclusion since we could not demonstrate that the fibers pass on uninterruptedly into the next section. They actually terminated at the margin of the cellular nodules in the material we studied.

Apparently, it is necessary to fix and section the tissues of Dupuytren's contracture in the manner employed in this study in order to demonstrate the abrupt ending of the aponeurotic fibers at the edge of a proliferating nodule. We do know from Skoog's illustrations that he prepared some of his tissues in this way. No other authors, except Nézelhof and Tubiana, stated whether they handled their tissues so that the plane of the section was parallel to the long axis of the fibers. Certainly, we were not able to observe the abrupt ending of the fibers in our first series, in which no special attention was paid to the plane of the section. Perhaps this explains why this observation has not been made more frequently. It should be stated, however, that Nézelhof and Tubiana did not observe the abrupt interruption of fibers in tissues that were prepared and sectioned in the same manner as ours.

The palmar and plantar aponeurosis of the monkey after experimental rupture showed similar abruptly terminating fibers at the margins of the cellular nodules. The experimental lesion of the anterior rectus sheath of the dog also had this appearance. Quite clearly, the termination of the collagen fibers in the palmar or plantar aponeurosis of the monkey and in the dog's rectus sheath was due to rupture of these fibers at the time of the experimental operation.

The fibroplasia present in the four types of tissue we described here (Dupuytren's contracture, Case 1, and the experimental lesions of the monkey and the dog) appears to be essentially the same. The maturation of the proliferating areas of Dupuytren's contracture and of the experimental lesions in the monkey and the dog was also histologically identical.

In each lesion hemosiderin deposits were demonstrated. In Case 1, in the monkeys, and in the dog the hemosiderin was quite clearly the result of hemorrhage into the areas at the time the fibrous tissue was injured. The presence of hemosiderin in the immature lesions of Dupuytren's contracture cannot be logically explained in any other way. In the monkey, the hemosiderin deposits are rare in specimens removed nine months after rupture of the fascia. In Dupuytren's contracture, they are found only in the most immature areas of cellular proliferation. Often, the hemosiderin granules appear to be within phagocytes; presumably, they are removed slowly from the proliferating area by the phagocytes.

Some authors did not find hemosiderin deposits in their specimens, whereas others stated that hemosiderin is only rarely or infrequently present [7]. Often, the granules are very fine and few in number; close search and high magnification (×400) are necessary in many sections before their presence can be demonstrated. In addition, they can be found only in the most immature cellular areas. Not all specimens of Dupuytren's contracture will contain these immature cellular areas. Furthermore, hemosiderin is removed from the tissues by acid fixatives that do not contain formalin and is also removed to some extent by acid formalin. One or more of these factors may explain the variations in the findings of different authors with respect to hemosiderin deposits in the proliferative phases of Dupuytren's contracture.

Metachromatic staining was observed in the proliferating areas of the experimental lesions of the monkey and in the areas containing immature fibrous tissue in Dupuytren's contracture. The metachromatic property of the less mature tissues indicates the presence of polymerized mucopolysaccharides, probably chondromucins or chondroitin sulphuric mucins. These compounds are believed to be essential components of the ground substance. Because amyloid is also a type of chondroitin-sulphuric-acid-protein complex, the tissues were stained for amyloid, but no amyloid was found in any of the monkey or human tissues. The metachromatic staining of the cellular areas of Dupuytren's contracture was observed by several authors[6,9,11]. At the present time, metachromasia in the cellular stages of Dupuytren's contracture is only an interesting observation which really contributes little to our understanding of the pathogenesis of the disease.

Lagier and Rutishauser and Skoog observed that the "hyalinized" collagen fibers of Dupuytren's contracture stain red with Mallory's connective-tissue stain. Similar red staining of hyalinized tissue in other fibrotic lesions, such as perisplenitis, was not observed by Lagier and Rutishauser. We, too, observed that the fibers in the very dense mature areas of the contracture stain red instead of blue with Mallory's stain. The significance, if any, of this staining reaction remains obscure.

The very finest fibers in the proliferating areas do not take the orange stain

of hematoxylin and eosin but rather had a pale lavender color. These fibers do not take the green stain of the Masson connective-tissue stain. Probably, these are reticulin fibers. We did not do specific stains for reticulin. Nézelhof and Tubiana found marked staining of the intercellular areas with the Hotchkiss method (one of the periodic acid-Schiff techniques). This would seem to indicate the presence of reticulin in the intercellular areas.

The vascular proliferation observed in the tissue from both human Dupuytren's contracture and monkey lesions seems to be similar. The intimate relationship between the vessels and the proliferating fibroblasts in Dupuytren's contracture has often been observed [5-7]. If human Dupuytren's contracture begins as an injury to the palmar fascia similar to the injury produced in the monkeys in these experiments, then the increased capillary vascularity noted in the proliferating nodules of tissue in human Dupuytren's contracture must be the same type of response noted in the monkey. At first, as the fibroblastic proliferation in the area of rupture of the aponeurosis proceeds there is an accompanying proliferation of angioblastic tissue with the formation of new capillaries, but in both the monkey and the human lesions the increase in capillary vascularity is no longer present when the mature scarlike state is reached.

It is generally known that in wound healing, differentiated or mature connective tissues cannot dedifferentiate and give rise to more immature forms of tissue. The fibroblasts that appear at the site of injury are derived from nests of cells around the blood vessels. As these fibroblasts migrate into the site of injury they are accompanied by new capillaries [4].

This process seems to us to explain quite readily the sequence of events observed in the healing of the monkey lesions. It would also account for the frequent observation that the immature fibroblasts of Dupuytren's contracture appear to arise from the wall of nearby vessels.

Caution should be used in trying to correlate the experimentally induced lesion in a monkey with that of human Dupuytren's contracture. We have no assurance that the monkey lesion would progress to the formation of a contracture even if the lesion were reproduced repeatedly over a long period of time. Furthermore, we do not know if trauma is the only agent capable of producing the type of response that we produced in the monkey's palmar and plantar fascia. Other agents may be able to produce a similar lesion.

Finally, it is in no way established that the monkey lesion is comparable to human Dupuytren's contracture with respect to the magnitude of the trauma involved. Considering the total size of the palmar fascia of a monkey, it is evident that a great deal of trauma to the fascia was produced by our experimental operation. Certainly, nothing so severe as this occurs at the time of the supposed microrupture of human palmar fascia.

Much of the nature and behavior of connective tissue remains unknown. The composition of the connective tissues of the aged is known to be different in certain respects from that of younger persons [1] and the healing of connective tissue is altered by various nutritional and endocrine disorders. In addition, connective tissues do not always respond in the same way to the same stimulus; the state of the organism may alter the response of the tissues to a given stimulus [3].

In the light of the preceding statements, it seems possible that certain individuals have some alteration of their connective tissues that causes these tissues to respond in an abnormal manner. It may be that their collagen fibers are more susceptible to microruptures. Possibly, in regular daily life, we all sustain microruptures of the collagen fibers, but only certain individuals hyperreact with profuse fibrous-tissue proliferation. The conditions or diseases that may alter the

connective tissue in this way are not known, except for age, hereditary factors, and, perhaps, sex.

If it is true that in certain persons there is a predisposition for the contracture to develop, we must then find the stimulus that starts its development. Since the lesion produced experimentally in the monkey appears to us to be the same as that seen in the proliferating nodules of Dupuytren's contracture, it would appear that partial rupture of the fibers of the palmar aponeurosis is one stimulus that may initiate the development of the proliferating nodules characteristic of the early stages of Dupuytren's contracture. The fibrous-tissue nodule encountered in the patient in Case 1 was apparently produced by laceration of the palmar fascia with glass. It is, as far as we can determine, histologically identical to the early lesions of Dupuytren's contracture. This observation lends additional weight to the assumption that this kind of cellular response can be provoked by division of the fibers of the palmar aponeurosis. Whether partial rupture of the aponeurotic fibers is the only stimulus that can start this lesion, either in the human being or in the monkey, is not known.

CONCLUSION

We can therefore summarize the pathogenesis or mode of development of the experimental lesion produced in the monkey as follows: A partial tearing of the collagen fibers in the palmar or plantar aponeurosis occurs, followed by hemorrhage into the area. Perivascular fibroblasts proliferate and invade the ruptured area. Fine new collagen fibers are formed, which ultimately become arranged into thick fascicles of dense collagen fibers. As the fibroblasts invade the area, new capillaries accompany them. When the mature stage of the lesion is reached, the number of vessels is markedly reduced. Metachromatic staining of the cellular areas with toluidine blue is present at first but this finding is not present in the more advanced stages of the lesion. Hemosiderin is gradually removed from the cellular areas by phagocytes. The newly formed fibers are collagen and not elastic-tissue fibers. Finger contracture does not develop in the monkey.

The lesion produced in the monkey is, as far as we could determine, histologically the same as one of the proliferative lesions encountered in Dupuytren's contracture. The staining reactions of the two lesions with hematoxylin and eosin, iron stains, toluidine blue, Bennhold's Congo red, Mallory's and Masson's connective-tissue stains, and Verhoeff's elastic-tissue stain are the same. The early cellular stages, the intermediate stages of maturation of the fibrous tissue, and the final stage of dense collagen fiber formation were all recognizable in both lesions.

SUMMARY

1. Sixty-nine additional specimens of Dupuytren's contracture have been studied. These specimens were fixed with the fascia under normal tension and sectioned longitudinally.

2. The lesion of Dupuytren's contracture begins as an area of fibrous-tissue proliferation and ends as a band of thick collagen fibers. Hemosiderin deposits in the cellular areas are believed to be evidence of previous hemorrhage into the areas. Abrupt termination of collagen fibers at the edge of the cellular nodules has been observed.

3. Partial rupture of the palmar and plantar fascia was produced in twelve monkeys, together with appropriate control operations. By this method a lesion which resembles the cellular stages of Dupuytren's contracture has been produced. The monkey lesion matures into dense collagenous tissue in the same way that the

cellular stages of Dupuytren's contracture mature. Contracture of the finger did not develop in the monkeys in these experiments.

4. One patient has been encountered in whom a nodule developed within the palmar fascia after laceration of the fascia. The nodule had the microscopic characteristics of the cellular stage of Dupuytren's contracture.

5. A similar fibrous-tissue proliferation has been provoked by partial rupture of the anterior rectus sheath of a dog. The response in the dog was less intense than in the monkey and the lesion healed more rapidly.

6. These observations lead us to believe that partial rupture of the palmar aponeurosis is one way in which the type of fibrous-tissue proliferation observed in Dupuytren's contracture can be provoked.

REFERENCES

1. Banfield, W. G.: Aging of Connective Tissue, p. 151. *In* Connective Tissue in Health and Disease. Edited by G. Asboe-Hansen. Copenhagen, Ejnar Munksgaard, 1954.
2. Dupuytren, Guillaume: Leçons Orales de Clinique Chirurgicale. Lecture delivered at l'hôtel-Dieu, Paris, during the Session of 1833. Translated into English: Permanent Retraction of the Fingers, Produced by an Affection of the Palmar Fascia. Lancet, **2**: 222–225, 1834.
3. Fremont-Smith, Frank: *In* Effect of ACTH and Cortisone on Connective Tissue, p. 160, by Charles Ragan. *In* Connective Tissues. Transactions of the First Conference, April 24–25, 1950, New York, N. Y. Edited by Charles Ragan. New York, Josiah Macy, Jr. Foundation, 1950.
4. Howes, E. L.: The Connective Tissues in Wound Healing, p. 159. *In* Connective Tissue in Health and Disease. Edited by G. Asboe-Hansen. Copenhagen, Ejnar Munksgaard, 1954.
5. Janssen, Peter: Zur Lehre von der Dupuytren'schen Fingercontractur, mit besonderer Berücksichtigung der operativen Beseitigung und der pathologischen Anatomie des Leidens. Arch. f. Klin. Chir., **67**: 761–789, 1902.
6. Lagier, R., and Rutishauser, E.: Anatomie pathologique et pathogénie de la maladie de Dupuytren. Presse Méd., **64**: 1212–1216, 1956.
7. Larsen, R. D., and Posch, J. L.: Dupuytren's Contracture. With Special Reference to Pathology. J. Bone and Joint Surg., **40-A**: 773–792, July 1958.
8. Lillie, R. D.: Histopathologic Technic and Practical Histochemistry. Ed. 2. New York, McGraw-Hill Book Co. Inc., 1954.
9. Nézelhof, C., and Tubiana, R.: La maladie de Dupuytren. Étude histologique. Semaine Hôp. Paris, **34**: 1102–1110, 1958.
10. Pedersen, H. E., and Gardner, E. G.: Personal communication of unpublished data.
11. Skoog, Tord: Dupuytren's Contraction. With Special Reference to Aetiology and Improved Surgical Treatment. Its Occurrence in Epileptics. Note on Knuckle-Pads. Acta. Chir. Scandinavica, **96**: Supplementum 139, 1948.
12. Skoog, Tord: Dupuytren's Contracture. Postgrad. Med., **21**: 91–99, 1957.

DISCUSSION

Dr. J. M. Bruner, Des Moines, Iowa: At this meeting two years ago, Dr. Larsen presented his first paper on the pathogenesis of Dupuytren's contracture. Again, we are indebted to him for a well planned clinical and experimental study of this condition, for a beautiful microscopic depiction of the histopathology, and for an interesting cine-demonstration of his animal experiments.

The observation in the microscopic sections of two types of tissue, the immature and the mature; the absence of elastic fibers; the presence of hemosiderin pigment, suggesting hemorrhage; and the abrupt termination of fibers, suggesting rupture, are all exceedingly provocative.

It seems fairly well accepted that Dupuytren's contracture arises in predisposed persons, many of whom give a family history of the same condition. If there is also a traumatic factor, the question arises as to what kind of trauma this may be. Evidently, Dr. Larsen and Dr. Posch believe that this trauma is in the nature of tension stretching or rupture of the fascia rather than the direct trauma to the palm sustained by the manual laborer or the baseball or handball player.

Two cases in point may be cited:

Case 1. A woman, fifty years old, fell on her outstretched palm and sustained a Colles' fracture. When she fell, she bent her fingers backward violently, thus causing severe pain in the palm. Soon after this, a thickening appeared in the distal part of the palm that gradually produced contracture of the long and ring fingers. Fasciectomy was done and examination of the resected specimen showed tissue characteristic of Dupuytren's contracture.

Case 2. A hospital employee, forty-five years old, had advanced Dupuytren's contracture involving the ring and little fingers. He stated that the progress of the contracture was quite gradual, but when he started to forcibly and violently straighten the fingers many times a day, there was very rapid progress of the contracture. Fasciectomy was done, with the usual findings. Unfortunately, hemosiderin deposits were not looked for in the resected tissue.

In Case 1, a single episode of stretching appeared to be the inciting factor; in Case 2, repeated stretching seemed to be an aggravating factor. However, these were the only two cases seen during the past ten years in which the patient remembered any specific trauma. It is likely, therefore, that if rupture of fibers is the causative factor in predisposed persons, it must be minor in nature but repeated over a period of years.

In support of this theory are certain facts as to the distribution of Dupuytren's contracture in the human palm, the ring finger being first and the little finger second in frequency of involvement. Consideration of the dynamic factors causing stress and strain in the palmar fascia is most significant.

The hand consists of three elements or pillars, a radial element (the first metacarpal), which is freely movable; a central element (the second and third metacarpals), which is relatively fixed in relationship to the carpus; and an ulnar element (the fourth and fifth metacarpals), which has moderate but restricted mobility. The second and third carpometacarpal joints are relatively solid; the fourth and fifth have some mobility.

Longitudinal stress in the palmar fascia is produced by hyperextension of the fingers and is greatest in the ulnar element of the hand. When the fist is clenched, a torsion of the metacarpophalangeal axis occurs; this is reversed when the hand is widely opened. Range of hyperextension, as well as flexion, is greatest in the metacarpophalangeal joint of the little finger, slightly less in the ring finger, and progressively less in the long and index fingers.

Transverse stress in the palmar fascia is produced by intermetacarpal movement and this is greatest between the fixed and the movable pillars of the hand, that is, near the base of the ring finger. This coincides with the point at which the greatest hyperplasia of the palmar fascia is seen clinically.

Advancing age and a sedentary occupation are also probably important in rendering the fascial tissue more vulnerable to tension. This may explain why white-collar workers may be more susceptible to the trauma of stretching of the palmar fascia than manual laborers, whose aponeurosis undoubtedly has greater tensile strength.

DR. S. BENJAMIN FOWLER, NASHVILLE, TENNESSEE: In considering the etiology of any disorder, and Dupuytren's contracture is no different no matter how beautiful the microscopic sections and how beautiful the work is, I have to think of the patient as a whole and his environment. I live in a section of the country that has a large Negro population and I have never seen Dupuytren's contracture in a Negro. I suppose it does occur. There are many Negroes who have "white blood", but I have never seen it in the light-colored Negro. Dupuytren's contracture usually does not exist as an isolated lesion: there is usually a pathological condition elsewhere in the body.

DR. LARSEN (closing): We did not intend to imply that microrupture of the fascia was the only etiological factor operative in Dupuytren's contracture. In the body of this paper it has been pointed out that microrupture of the palmar fascia may be one of the triggering mechanisms that starts the formation of the contracture in a person who has some type of predisposition that makes the palmar fascia susceptible to the contracture. We do see Negro patients with Dupuytren's contracture and Dr. Takagishi tells us that he has seen Dupuytren's contracture in the Japanese.

Amino-Acid Chromatography and Transaminase Activity in Denervation Atrophy*†

BY PINCKNEY J. HARMAN, PH.D., JERSEY CITY, NEW JERSEY, AND
J. L. MAGNANI, PH.D., S. D. SANWAL, M.D., AND
W. A. L. THOMPSON, M.D., NEW YORK, N. Y.

From the Departments of Anatomy and Orthopaedic Surgery, New York University-Bellevue Medical Center, New York, and the Department of Anatomy, Seton Hall College of Medicine and Dentistry, Jersey City

A recurring problem in the chemical analysis of biological material concerns the isolation of individual compounds from complex mixtures. Such separations may be very effectively accomplished by the technique of chromatography. Chromatography exploits the potent resolving power of differential adsorption and differential solubility to bring about the localization of chemical compounds. Such localization is so highly characteristic for individual compounds—even for those of closely related structure, such as the various amino acids—that chromatography has become increasingly the technique of choice in analytical studies. Chromatographic procedures of several different types effect the localization of individual compounds on a stationary phase from a moving solvent carrying the mixture under analysis. The demonstration by Consden, Gordon, and Martin in 1944 that filter paper will serve as a satisfactory stationary phase for chromatographic separations has greatly simplified this powerful analytic procedure. These authors showed that effective separations could be achieved if mixtures of chemical compounds in suitable solvents were allowed to migrate across the face of filter paper. Subsequent studies of the behavior of amino acids on filter paper [4,6,7] made available a relatively uncomplicated and reliable method for the investigation of amino nitrogen compounds present in tissues and organs in health and disease.

A study of amino acids in normal and degenerated nerve in this laboratory has indicated that the pattern of free amino acids provides a sensitive index of the functional integrity of nervous tissues. The present report deals with the free amino acids and their related enzymes, the transaminases, in normal muscle and in muscle undergoing denervation atrophy.

METHOD

Rats of an inbred strain, weighing from 334 to 439 grams, were used in a study of free amino acids and of glutamic-oxaloacetic and glutamic-pyruvic transaminases. Mice from the 129 strain of the Roscoe B. Jackson Memorial Laboratory, weighing between 12.5 and 20.3 grams, were used in an additional investigation of the glutamic-oxaloacetic transaminase system.

Unilateral denervation atrophy in the muscles of the gastrocnemius-soleus complex was induced as follows: With the animal under light ether anesthesia and with aseptic precautions, a one-half-centimeter segment (in the mouse) or a one-centimeter segment (in the rat) of the sciatic nerve on one side was excised at the level of the greater trochanter of the femur and the ischial tuberosity.

*Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 24, 1959.

† This investigation was supported by research grants from the Sister Elizabeth Kenny Foundation, the Muscular Dystrophy Associations of America, Inc., and by Grants B-151, B-1222, and B-1634, National Institute of Neurological Diseases and Blindness, Public Health Service.

Reinnervation of the distal musculature was obviated by retrograde suture of the central nerve stump into proximal musculature. Absence of reinnervation was verified by dissection at autopsy and by reference to the ensuing weight loss in the gastrocnemius-soleus muscles.

After decapitation and exsanguination, the gastrocnemius-soleus muscles were removed and quickly weighed on a Roller-Smith torsion balance. Only muscles from animals free from signs of postoperative infection, edema, or venous congestion were reserved for analysis.

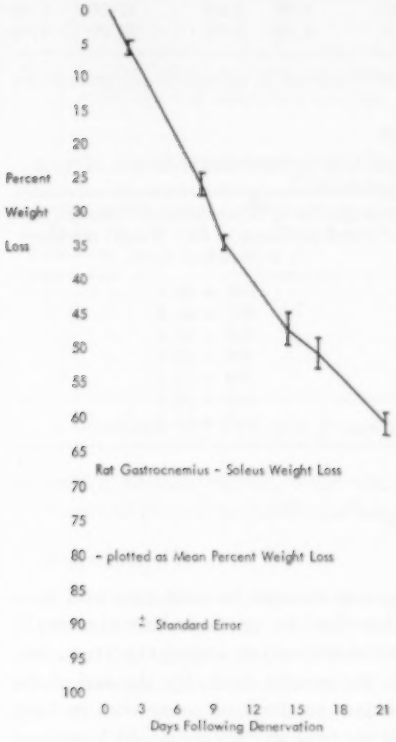


CHART I

Weight loss of rat muscle during denervation atrophy.

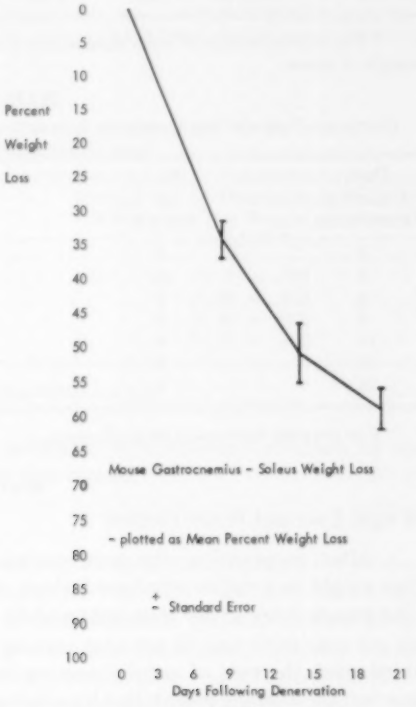


CHART II

Weight loss of mouse muscle during denervation atrophy.

Water content was determined in both normal and atrophic muscles by comparison of the fresh muscle weights with weights of the same muscle after dessication to a constant weight.

Free amino acids were extracted from fresh samples of muscle with 70 per cent ethanol and separated by 2-dimensional descending paper chromatography [5], using 80 per cent propanol and water-saturated phenol as solvents. Amino acids were identified by relative position after visualization with 0.2 per cent ninhydrin in 95 per cent ethanol. After maximum color development, the concentration of individual amino acids was evaluated by elution with 50 per cent ethanol and colorimetric estimation in a Lumitron Model 401-A colorimeter.

Glutamic-oxaloacetic and glutamic-pyruvic transaminase activities in rat muscle were determined by the chromatographic method of Awapara and Seale; glutamic-oxaloacetic transaminase activity in mouse muscle was estimated by the spectrophotometric method of Karmen and associates.

TABLE I

FREE AMINO ACIDS IN DENERVATION ATROPHY*

Duration of Atrophy (Days)	Alanine		Glutamic		Serine		Taurine	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
0	13.80	7.50	7.00	2.50	6.70	2.00	20.00	9.00
3	13.00	9.70	7.00	1.60	2.90	1.60	32.00	10.00
8	31.20	15.60	7.65	2.10	2.40	1.60	29.00	9.00
12	48.00	30.80	4.66	3.00	1.76	0.80	14.00	10.00
16	53.00	30.00	7.16	4.66	4.80	2.68	17.00	5.00
22	57.00	17.00	9.80	3.34	4.80	2.40	23.00	9.00

* The concentrations of individual amino acids are expressed as micromoles per gram of dry weight of tissue.

TABLE II

GLUTAMIC-PYRUVIC TRANSAMINASE ACTIVITY OF THE RAT GASTROCNEMIUS-SOLEUS MUSCLE

Days Following Denervation	No. of Animals	Average No. of Micromoles of Glutamic Acid Formed per Gram of Dry Weight per Hour ± Standard Error
0	9	346 ± 45.3
3	10	297 ± 45.0
6	6	350 ± 66.5
9	6	435 ± 30.8
14	6	502 ± 72.8
16	6	390 ± 22.7
21	6	395 ± 41.2

p = between 0.10 and 0.50 in all cases.

RESULTS

Weight Loss and Water Content

After denervation, the gastrocnemius-soleus muscles in both rats and mice lose weight in a rather constant fashion, as described by previous investigators [10]. The muscle loses 25 per cent (rat) and 32.5 per cent (mouse) during the first week; 45 per cent (rat) and 50 per cent (mouse) by the second week. By the end of the third week the rate of muscle wasting has begun to diminish somewhat in both species; the average loss at this time being 60 per cent in the rat and 56.5 per cent in the mouse (Charts I and II).

Despite this precipitous fall in muscle weight, the wet-weight/dry-weight ratio was not appreciably altered during atrophy. The water content of both rat and mouse muscle remained at approximately 76 per cent in both normal and atrophic muscle, indicating that dehydration is not the only factor in the weight loss that characterizes denervation atrophy, loss of muscle solids being proportionate to the over-all weight loss.

Free Amino Acids

The concentration of the various free amino acids which may be detected and estimated readily in muscle by the method of 2-dimensional paper chromatography has been studied in normal and atrophic rat muscle (Table I). Examination of the data reveals that only free alanine is strikingly altered in concentration during the course of denervation atrophy, if the amounts of amino acid per gram of wet weight of normal and atrophic muscles are compared. Glutamic acid, its amide, glutamine, serine, and taurine showed no consistent change throughout atrophy. Free aspartic acid and glycine, although present in detectable amounts

TABLE III

GLUTAMIC-OXALOACETIC TRANSAMINASE ACTIVITY OF THE RAT GASTROCNEMIUS-SOLEUS MUSCLE

Days Following Denervation	No. of Animals	Average No. of Micromoles of Glutamic Acid Formed per Gram of Dry Weight per Hour ± Standard Error
0	9	720 ± 39.2
3	10	662 ± 37.0
6	6	644 ± 32.6
9	6	670 ± 14.5
14	6	800 ± 60.0
16	6	650 ± 47.0
21	6	668 ± 83.8

p = between 0.10 and 0.50 in all cases.

TABLE IV

GLUTAMIC-OXALOACETIC TRANSAMINASE ACTIVITY OF THE MOUSE GASTROCNEMIUS-SOLEUS MUSCLE

Days Following Denervation	No. of Animals	Average No. of Transaminase Units per Milligram of Dry Weight per Minute ± Standard Error
0	9	26.76 ± .732
7	7	25.01 ± .935
14	7	24.80 ± .820
21	7	25.06 ± .860

p = between 0.50 and 0.10 in all cases of denervation atrophy.

in normal skeletal muscle, could not be estimated with sufficient accuracy by the methods employed to justify inclusion in this report.

Transaminases

Both glutamic-oxaloacetic and glutamic-pyruvic transaminases were studied in normal and atrophic rat muscle (Tables II and III). Glutamic-oxaloacetic activity was roughly twice that of the glutamic-pyruvic system. Neither of the two enzyme systems showed any striking consistent alteration in activity during the course of atrophy, as computed on a dry-weight basis. As a further check on transaminase activity during atrophy, the glutamic-oxaloacetic system was investigated in atrophic mouse muscle, using a spectrophotometric [11] rather than a chromatographic [2] method (Table IV). This methodological change did not alter the results; glutamic-oxaloacetic transaminase activity of the mouse gastrocnemius-soleus muscle did not appear to be significantly altered from normal during the first three weeks of atrophy. It appears, then, that in both rat and mouse muscle no change in transaminase activity per unit of dry weight occurs, even when atrophy has advanced to the point that more than half of the original muscle weight has been lost.

DISCUSSION

A skeletal muscle, such as the gastrocnemius, should be recognized as a heterogeneous composite, rather than as a simple tissue. As in other organs, there is a complex composed of the specific muscle cell—the muscle parenchyma—and of the interstitial element—the muscle stroma—which consists of connective-tissue cells, fibers, ground substance, blood vessels, and nervous tissue. It is imperative to evaluate the relative proportions of parenchyma and stroma if quantitative comparisons of one muscle sample with another are desired. To this

end, in the past considerable attention has been directed toward determining suitable base lines that will reflect the well known variations occurring in various muscles of the same animal and in the same muscle from animals of the same and different species. In the present study the errors associated with these naturally occurring variables have been minimized by restricting the investigation to the gastrocnemius-soleus complex in two species of rodents, and by emphasizing side-to-side comparisons in the same animals within the same species.

Yet, the problem under consideration—the study of changes in muscle during denervation atrophy—necessitates comparing normal muscle of relatively stable structure with muscle undergoing atrophy, that is, with an organ in the process of continuous structural change. To appreciate better the significance of the changes taking place during atrophy for the interpretation of biochemical data, an analysis will be attempted of the effect of atrophy on the parenchyma and stroma of muscle.

Denervation atrophy during the first three weeks following neurotomy appears to be a relatively benign process, as compared with the dystrophies, in that the major change in atrophy occurs within the muscle cells without any obvious concomitant reaction of the stroma [1]. As Fischer reminds us, the "interstitial phase"—that is, the stroma—retains its absolute bulk during atrophy, and for this reason the amount of stroma becomes relatively larger as the whole muscle shrinks, whereas the "muscle phase"—that is, the parenchyma—undergoes an absolute and relative decrease. Under these conditions, equal amounts of normal and atrophic muscle will not contain the same proportions of parenchyma, and it may become necessary to correct quantitative data based on equal weights of muscle for the shift in percentage which occurs in the parenchyma-stroma ratios during atrophy. Another factor to be considered is that muscle cells are apparently not lost for a considerable period during atrophy, there being a notable absence of necrosis and phagocytosis [1]. In consequence, as atrophy progresses there is an increase in the number of muscle cells per unit volume; thus, if one wishes to refer biochemical data to cell populations, then correction factors that will allow for this increased cellularity should also be considered.

Changes in the parenchyma-stroma percentage in samples of equal size may be evaluated and, with them, the order of magnitude of any correction factors can be calculated. For example, a comparison may be made between a one-gram sample of normal gastrocnemius and a one-gram sample of a gastrocnemius muscle that has suffered a loss of half its weight through atrophy. The data previously mentioned, on water content of normal and atrophic muscle, indicate that the percentage of water content will be the same in both samples, and that the total solids, which contain the compounds of interest, will constitute some 24 per cent of both samples. The problem, then, reduces itself into a consideration of the changes occurring in the solid component during atrophy. Since the stromal portion of the solid component is not affected in absolute amount by atrophy, the concentration of the stromal solid component will be greater in atrophic than in normal samples. *Per contra*, the concentration of the parenchyma solid component decreases, necessitating a correction of the data in the opposite direction, that is, upward. Data from several sources [8] on the percentage decrease in parenchyma solid component during atrophy indicate that the following correction factors are relevant for various stages of atophy: at one week 1.1, at two weeks 1.3, and at three weeks 1.6.

In the case of the data on free amino acid, use of these correction factors will not result in any interpretations different from those based on equivalent weights. Free alanine elevations are only accentuated and, although the average values for the other amino acids become somewhat higher, in no case is the increase

sufficient to eliminate the overlap existing between the ranges of experimental and control values.

In the case of the transaminases, on the other hand, a revision of interpretations appears to be in order. As atrophy progresses, application of correction factors elevates the average activity values to above the normal range. Specifically, glutamic-pyruvic activity in rat muscle and glutamic-oxaloacetic activity in rat and mouse muscle are significantly increased at both two and three weeks of atrophy.

The question of muscle cells per unit volume is not so crucial as it might seem. Although there are actually more muscle cells in one gram of atrophic muscle than in normal, this increase in cellularity must be balanced against the decrease in muscle protoplasm known to occur in individual atrophic muscle cells. Actually, the increase in cell numbers is more than compensated for by the decrease in protoplasm. Since the cell content, rather than the cell number, is the significant variable, the amount of parenchyma per sample remains the best basis for reference.

More refined criteria for estimation of the active elements of the muscle cell, which are related to biochemical events, will undoubtedly emerge. Under present conditions, however, it seems that biochemical comparisons based on quantitative determinations may profitably be continued on either a wet-weight or a dry-weight basis in atrophy. Correction factors should receive careful consideration, and in the present study the introduction of such factors has necessitated new interpretations of the data in reference to transaminase activity.

The increase in free alanine during atrophy raises the question of whether the concentration of this amino acid should be included in laboratory studies of muscle disease. Tallan reported an increase in free alanine and other amino acids in dystrophic muscles of vitamin-E deficient rabbits; free alanine also increases markedly in amount in nerve undergoing Wallerian degeneration, as pointed out by Harman and associates. In a series of biopsies of the cat gastrocnemius (seven animals) performed in their laboratory, free alanine was found to be higher, without exception, in atrophic muscle than in the contralateral control. On the negative side, it should be noted that although the elevation of free alanine is striking, variation from animal to animal, in the earliest stage studied (three days), resulted in some overlap between normal and atrophic values. Since, however, in atrophy alanine is much more consistently elevated than the other amino acids, the pattern of free amino acids may prove to be useful in biopsy studies. In this connection it should be noted that free amino acids may be extracted with 70 per cent ethanol without homogenization of the muscle, and the tissue itself may be reserved for histological examination. Tallan also described a marked reduction in glycine concentration in nutritional dystrophy in the rabbit. This finding suggests that the glycine-alanine ratio, which was not considered in the present study because of the inadequacy of the method employed for a quantitative estimation of glycine, deserves further study, both in atrophy and in dystrophy.

Elevated transaminase activities at two and three weeks of atrophy also suggest analogies with dystrophy since Beckett and Bourne reported increased phosphatase activity (including 5-nucleotidase) in muscle biopsies from human patients, and Tassoni and Harman reported elevated succinic dehydrogenase activities in advanced stages in the muscles of the dystrophic mouse. Elevated enzyme activities in dystrophy, as in atrophy, may well be secondary phenomena and not necessarily related to the causation of physical changes observed in these two forms of muscular disorder. In the case of dystrophy, studies of succinic

dehydrogenase activity at early stages demonstrated that initial values may not show increased enzymatic action, and the heightened activities reported here in atrophy could also be demonstrated only after the atrophic process had been well established.

REFERENCES

1. Adams, R. D.; Denny-Brown, D.; and Pearson, C. M.: Diseases of Muscle. A Study in Pathology. Chaps. 3 and 6. New York, Paul B. Hoeber, Inc., 1953.
2. Awapara, Jorge, and Seale, Billie: Distribution of Transaminases in Rat Organs. J. Biol. Chem., **194:** 497–502, 1952.
3. Beckett, E. B., and Bourne, G. H.: Some Histochemical Observations on Human Dystrophic Muscle. Science, **126:** 357–358, 1957.
4. Block, R. J.; LeStrange, R.; and Zweig, G.: Paper Chromatography: A Laboratory Manual. New York, Academic Press, Inc., 1952.
5. Consden, R., Gordon, A. H., and Martin, A. J. P.: Qualitative Analysis of Proteins: A Partition Chromatographic Method Using Paper. Biochem. J., **38:** 224–232, 1944.
6. Dent, C. E.: The Amino-aciduria in Fanconi Syndrome. A Study Making Extensive Use of Techniques Based on Paper Partition Chromatography. Biochem. J., **41:** 240–253, 1947.
7. Dent, C. E.: A Study of the Behaviour of some Sixty Amino-acids and other Ninhydrin-reacting Substances on Phenol-'collidine', Filter-paper Chromatograms, with Notes as to the Occurrence of some of them in Biological Fluids. Biochem. J., **43:** 169–180, 1948.
8. Fischer, Ernst: Changes in Protein and Enzymes in Muscular Degeneration Subsequent to Denervation, pp. 212–222. *In* Proceedings of the Third Medical Conference of Muscular Dystrophy Associations of America, Inc., New York, N. Y., October 8 and 9, 1954.
9. Harman, P. J.; Rippe, M. A.; Tankard, M. G.; and Taswell, E. S.: In preparation, 1960.
10. Hines, H. M., and Knowlton, G. C.: Changes in the Skeletal Muscle of the Rat Following Denervation. Am. J. Physiol., **104:** 379–391, 1953.
11. Karmen, Arthur; Wróblewski, Felix; and LaDue, J. S.: Transaminase Activity in Human Blood. J. Clin. Invest., **34:** 126–133, 1955.
12. Tallan, H. H.: Free Amino Acids of Muscle of Normal and of Vitamin E-Deficient Rabbits. Proc. Soc. Exper. Biol. and Med., **89:** 553–555, 1955.
13. Tassoni, J. P., and Harman, P. J.: Alterations in Succinic Dehydrogenase Activity at Different Stages of Muscular Dystrophy in the Mouse. J. Neuropathol. and Exper. Neurol. (in press).

Opposition of the Thumb and Its Restoration*

BY BERNARD JACOBS, M.D., AND T. CAMPBELL THOMPSON, M.D., NEW YORK, N. Y.

From The Hospital for Special Surgery, New York

Opposition of the thumb is the most important component of normal hand function and its loss constitutes a significant disability. An opposable thumb is responsible for most of the power of pinch and of grasp. Without it, functions that we take for granted, such as writing, buttoning a jacket, tying shoelaces, and picking up a coin, become difficult and clumsy. Opposition may be lost as a result of poliomyelitis, peripheral-nerve injury, peripheral neuritis, or loss of local tissue about the thumb.

MECHANISM OF OPPOSITION

One speaks blithely of opposition without full appreciation of its attainment or complexity. It is not a simple movement produced by a single muscle, but, on the contrary, it is a complex movement, the result of motions in several planes produced by the combined actions of at least three of the thenar muscles. There are, and have been, many concepts of the mechanism of opposition.

Duchenne concluded from his exhaustive studies that opposition resulted from the combined actions of the abductor pollicis brevis, supplying most of the power, the flexor pollicis brevis, and the opponens pollicis. Bunnell and Kaplan affirmed Duchenne's conclusions. Kaplan, however, ascribed greater importance than did Duchenne to the abductor pollicis longus and extensor pollicis brevis in activating the sway of the thumb.

Bunnell described opposition as a combination of rotation and angulation occurring at the carpometacarpal and metacarpophalangeal joints, with the abductor pollicis longus and both extensors serving as stabilizers. Steindler [14] analyzed opposition as follows: first, extension produced by the two extensors; then abduction by the two abductors; and, finally, pronation by the opponens and the flexor pollicis brevis. Opposition, according to Grant, involves circumduction by the abductor pollicis brevis assisted by the adductor; rotation by the opponens and flexor pollicis brevis; and flexion produced by the flexor pollicis longus and brevis. Grant conceived of the opponens pollicis and the superficial head of the flexor pollicis brevis as a single functional unit, which he termed the *pronator pollicis*.

The flexor pollicis brevis has not been delegated any function in opposition by some anatomists. McGregor and Last were of the opinion that the abductor pollicis brevis and opponens pollicis are solely responsible for opposition. Grinker ascribed opposition to the opponens and adductor pollicis. Markee stated that opposition is principally the function of the opponens, but that it is initiated by the abductor pollicis longus and extensor pollicis brevis. Kaplan succinctly concluded, ". . . in the loss of thumb opposition no single muscle should be accused and least of all the opponens pollicis".

BASIC REQUIREMENTS FOR SUCCESSFUL TRANSPOSITION

It is quite clear that tendon transposition for the restoration of thumb opposition must, at least in part, simulate the combined action of several muscles.

* Read at the Annual Meeting of the American Society for Surgery of the Hand, Chicago, Illinois, January 1960.

There are several basic requirements for a successful transposition that shall be discussed.

Correction of Fixed Deformity

It is axiomatic that fixed deformity should be prevented, and that, if it is present, it should be corrected prior to, or at the time of, tendon transposition. The deformity that we most commonly encountered in hands with loss of opposition was an external-rotation contracture of the thumb. Adequate correction of this deformity may be obtained by rotation osteotomy of the first metacarpal.

Choice of the Motor

The literature reveals that at least eleven different tendons have been utilized as transplants for the restoration of opposition. In the vast majority of cases at The Hospital for Special Surgery the flexor sublimis to the ring or middle finger

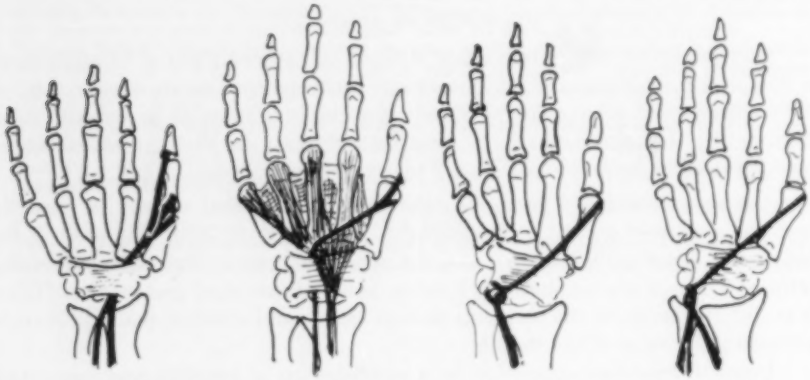


FIG. 1-A FIG. 1-B FIG. 1-C FIG. 1-D

Fig. 1-A: Motor: flexor digitorum sublimus (Royle) or flexor pollicis longus (Steindler). Pulley: transverse carpal ligament.

Fig. 1-B: Motor: flexor digitorum sublimis, ring or long finger (Thompson). Pulley: transverse carpal ligament and palmar aponeurosis.

Fig. 1-C: Motor: pollicis longus or flexor carpi ulnaris by way of free graft or extensor pollicis brevis. Pulley: free graft or one-half flexor carpi ulnaris.

Fig. 1-D: Motor: flexor digitorum sublimis or pollicis longus by way of free graft. Pulley: flexor carpi ulnaris.

was employed. The usual practice has been to transfer a tendon whose muscle has been rated as *good* or *better* whenever possible. Occasionally, it has been deemed preferable to use a muscle with power rated as less than *good* rather than to resort to some form of arthrodesis to restore opposition.

Construction of the Pulley

To reproduce true opposition it is desirable to construct a pulley that: (1) is securely fixed; (2) is in such a position that the motor tendon approaches its insertion at as near a right angle to the long axis of the thumb as possible, since the magnitude of the force exerted at the point of tendon insertion varies directly with the angle of insertion up to 90 degrees; and (3) is at a sufficient distance from the thumb to permit enough excursion of the transplanted tendon to produce an adequate range of opposition.

These requisites are thoroughly satisfied by the pulley created by one of us (T.C.T.), utilizing the junction of the distal margin of the volar carpal ligament with the ulnar border of the palmar aponeurosis (Fig. 1-B). This resembles the method introduced earlier by Ney. Bunnell stated that the pulley had to be at, or adjacent to, the pisiform to produce true opposition, and used the flexor carpi

ulnaris for this purpose (Figs. 1-C and 1-D). Radial migration of this type of pulley has been observed, but, in the opinion of some authorities, it is thought to be capable of permitting greater abduction than the Thompson pulley. Bunnell, in fact, reported that the latter method was incapable of producing true opposition except in some cases of poliomyelitis with marked laxity of the transverse carpal ligament. Our results demonstrate that the successful restoration of opposition in poliomyelitic patients is the rule rather than the exception when the Thompson pulley is used.

Both Royle and Steindler [13], pioneers in tendon transposition for the restoration of opposition, made use of the flexor pollicis longus (Fig. 1-A). Steindler used a split portion of the tendon, whereas Royle transposed the tendon of the flexor digitorum sublimis of the ring finger along the flexor pollicis longus sheath. In

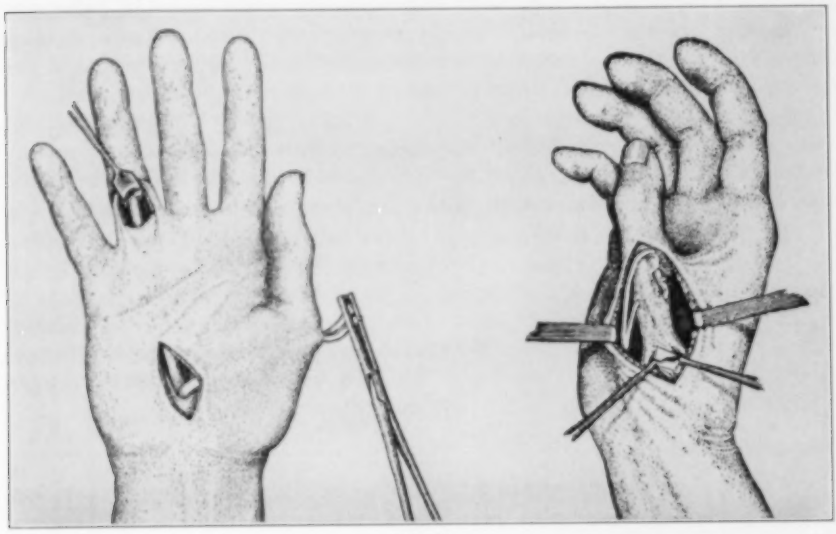


FIG. 2

Subcutaneous passage of the motor tendon (flexor sublimis) and attachment of separate slips to the metacarpal neck and base of proximal phalanx. The site of osteotomy is also shown.

both of these procedures, the pulley is too close to the thumb, and the motor tendon forms too acute an angle with the long axis of the thumb to be sufficiently effective. These procedures have thus frequently yielded disappointing results. The passage of two tendons through the same sheath, as advocated by Royle, is difficult and often results in the formation of adhesions between the two tendons.

Insertion of the Motor Tendon

There is general agreement that subcutaneous passage of the motor tendon in the palm gives the best results. There is no such unanimity of opinion concerning the best method of insertion of the tendon. As already indicated, from a mechanical standpoint, the more acute the angle of insertion, the weaker the force acting at that point. At this hospital many variations of tendon insertion have been employed. The most popular method, introduced by Royle and developed by one of us (T.C.T.), involves insertion of one slip of the flexor sublimis to the metacarpal neck and the other to the base of the proximal phalanx (Fig. 2). Bunnell preferred insertion onto the dorso-ulnar aspect of the base of the proximal phalanx. More recently, Riordan made popular a method of insertion in which the trans-

plant is attached to the tendon of the abductor pollicis brevis and to the expansion of the extensor pollicis longus.

Each of these three basic methods of tendon insertion is capable of producing good results. In our opinion, the success of any operation to restore opposition is not so much related to the precise method of insertion as to the proper selection of a good motor and the insertion of the tendon transplant under adequate tension. The latter is best accomplished by fixation of the tendon with the thumb held opposite the long finger in as much medial rotation as is possible.

ANALYSIS OF RESULTS

There were 120 tendon operations for the restoration of opposition of the thumb on 110 patients at The Hospital for Special Surgery from 1941 to 1958. In all but three of these 110 patients, loss of opposition was caused by poliomyelitis. In these three the disability was of traumatic origin in two and of congenital origin in one. Nothing of significance was apparent in the side involved or in the sex incidence. Seventy-eight patients were operated on by the Resident Staff, and the remainder by the Attending Staff. Ninety-six patients, representing 103 operations, returned for follow-up examinations. Both the range of true opposition and its power were considered in the rating of results. The average length of follow-up was five and a half years, with a minimum of eighteen months.

The criteria for the classification of results were as follows: Good or excellent results were those with at least 75 per cent of the function of the opposite thumb when normal or those with less than 20 degrees of difference between the plane of the opposed thumb nail and the plane of the palm, with good power. Fair results were those with good rotation of the thumb and poor power or those with less rotation and good power. Poor results (failures) included those with no thumb rotation or those with slight thumb rotation and poor power.

Good or Excellent Results

Seventy-seven results were rated *good* or better. The average age at operation of these patients was seventeen years; their ages ranged from four to thirty-six years. The average time from the onset of poliomyelitis to operation was six years. The flexor sublimis tendon of the ring finger was transposed in fifty instances, and the sublimis tendon of the long finger was used in twenty-three instances; the flexor profundus tendon of the little finger was used in three instances. In one instance the flexor carpi ulnaris was used as the motor and was prolonged by a graft obtained from the extensor tendon of the fourth toe. The Thompson pulley was employed in seventy-two instances, and the Bunnell pulley in five instances. Insertion of the motor tendon was to the base of the proximal phalanx alone in two instances, to the metacarpal neck alone in six, to the abductor pollicis brevis tendon and extensor pollicis longus expansion in twenty-one, and by a dual insertion into both the proximal phalanx and the metacarpal in forty-eight instances. Osteotomy of the first metacarpal was performed in eleven instances, and a plastic procedure on the first web space to release a soft-tissue contracture was done in two instances.

Fair Results

In nine instances the results were rated *fair*. The average age of the patients was sixteen years; their ages ranged from six to forty-one years. The average time from the onset of poliomyelitis to operation was eleven years. The flexor sublimis tendon of the ring finger was transposed in five instances, and the sublimis tendon of the long finger was used in two cases. A Steindler flexorplasty

TABLE I

		GOOD EXCELLENT	FAIR	POOR FAILED	TOTAL
TYPE OF PULLEY	THOMPSON	72	7	15	94
	BUNNELL	5	1	1	7
	STEINDLER	–	1	1	2
MOTOR USED FOR TRANSPLANT	FL. Dig. Sub. 4th	50	5	9	64
	FL. Dig. Sub. 3rd	23	2	4	29
	FL. Carp. Uln.	1	1	1	3
	FL. Dig. Prof. 5th	3	–	–	3
	FL. Dig. Prof. 4th	–	–	1	1
	Palm. Long.	–	–	1	1
STRENGTH OF MOTOR	GOOD OR BETTER	77	7	8	92
	LESS THAN GOOD	–	2	9	11
INSERTION OF TRANSPLANT	DUAL	48	5	11	64
	ABD. POLL. BREV.	21	–	3	24
	META. NECK	6	3	3	12
	PROX. PHALANX	2	1	–	3
RESIDUAL MUSCLE POWER ABOUT THE THUMB (pre-op.) 71 cases	ADD. POLL. > FAIR (MORE THAN FAIR)	34	4	3	41
	" " ≦ " (FAIR OR LESS)	21	2	7	30
	FLEX. POLL. LONG. > "	46	6	7	59
	" " " ≦ "	9	–	3	12
	ABD. POLL. LONG. > "	19	–	–	19
	" " " ≦ "	36	6	10	52
	EXT. POLL. LONG. > "	35	–	9	44
	" " " ≦ "	20	6	1	27
	FIRST DORS. INT. > "	19	1	–	20
	" " " ≦ "	36	5	10	51
ADJUVANT PROCEDURES	OSTEOTOMY OF FIRST METACARPAL	11	2	6	19
	PLASTIC PROCEDURE TO THUMB WEB	2	0	1	3
SURGEON	CASES OPERATED ON BY VISITING STAFF	22	1	–	23
	" " " RESIDENT	55	8	17	80
AGE AT OPERATION	≦ 12 years	26	2	1	29
	12 - 20 years	31	3	6	40
	> 20 years	20	4	10	34
TIME INTERVAL (ONSET TO OPERATION)	≦ 4 years	37	5	5	47
	4 - 10 years	28	1	7	36
	> 10 years	12	3	5	20

was performed in one instance. In one instance the flexor carpi ulnaris was used as the motor and was prolonged by a tendon graft obtained from the extensor tendon of the fourth toe. The Thompson pulley was employed in seven instances, and the Bunnell pulley in one instance. Insertion of the tendon transplant was to the metacarpal neck alone in three instances, to the proximal phalanx alone in one instance, and to both the proximal phalanx and metacarpal in five instances. Osteotomy of the metacarpal was performed in two instances.

Poor Results or Failures

In seventeen instances the results were rated *poor* or *failures*. The average

age of the patients was nineteen years. Their ages ranged from six to forty years. The average time from the onset of poliomyelitis to operation was nine years. The flexor sublimis of the ring finger was transposed in nine instances, and the sublimis tendon of the long finger was transplanted in four instances. The flexor profundus tendon of the ring finger was used in one instance, and a Steindler flexorplasty was done in one instance. In two instances the flexor carpi ulnaris and palmaris longus were used as the motor, and their tendons were prolonged by tendon grafts obtained from the extensor tendon of the fourth toe. The Thompson pulley was employed in fifteen instances, and the Bunnell pulley in one. Insertion was to the metacarpal alone in three instances, to the abductor pollicis brevis tendon and the expansion of the tendon of the extensor pollicis longus in three instances, and to both the metacarpal and proximal phalanx in eleven instances. Osteotomy of the metacarpal was performed in six instances, and a plastic procedure to release the web space was done in one instance. Despite the poor rating from the surgeon's viewpoint, only three patients thought that they had not been benefited by their operation. It is believed that the subjective improvement in function was due to potentiated power of apposition. Revisions of the transplants were performed in four instances, and the results were subsequently rated *good* in three; the result of the fourth case is not known. Revisions included two Thompson procedures, one Bunnell procedure, and one Steindler procedure. In each a new flexor sublimis tendon was employed as the motor with the pulley devised by Thompson. Dual insertion was used in three and as advocated by Riordan in one. Osteotomy of the metacarpal was performed in one.

ADJUVANT PROCEDURES IN THE RESTORATION OF OPPOSITION

The procedure of choice at this hospital for the correction of external rotation contracture of the thumb has been rotational osteotomy of the first metacarpal to place the thumb in a more advantageous position for opposition. The osteotomy is performed at the base of the metacarpal and the distal fragment is rotated medially 20 to 30 degrees. Osteotomy was performed in twenty-three instances—in eight instances as a separate procedure prior to tendon transfer, and in fifteen instances at the same time as the transfer. Eleven patients received a rating of *good* or better; in eight of these the osteotomy and tendon transfer were performed concurrently. Osteotomy was performed transversely at the metacarpal base. A drill hole was placed on each side of the osteotomy line in such a manner that each lay in the same longitudinal plane after the desired medial rotation of the distal fragment had been achieved. Position was maintained by a catgut suture placed through the drill holes. There were two fair results and six poor results.

A plastic procedure on the thenar web space for correction of contracture was performed in three instances. With respect to the tendon transfer, two of these procedures had good results, and one was a failure.

COMPLICATIONS

Donor-Tendon Finger

Flexion contracture at the proximal interphalangeal joint occurred in eight fingers in which the remaining portion of the distal sublimis tendon was too long. This complication may be avoided by daily full passive extension of the interphalangeal joint after operation. Hyperextension of the proximal interphalangeal joint was noted in one finger. There was one instance of a flail finger consequent to mistaken muscle rating.

Thumb

In the thumb, the most common problem that was encountered in five pa-

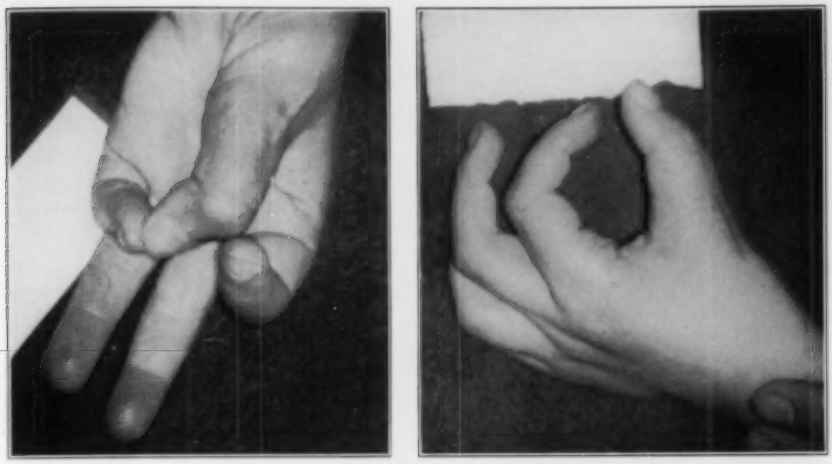


FIG. 3

There were two instances of mild hyperextension of the metacarpophalangeal joint.

tients was instability of mild to moderate severity of the metacarpophalangeal joint. Despite this instability, three of these results were rated as *good*, and two rated *fair*. Flexion deformity of the metacarpophalangeal joint occurred in two instances due to insertion of the motor tendon too far distal on the proximal phalanx. One result was rated *fair*; the other was rated *poor*, and the patient required arthrodesis of the joint. There were also two instances of mild hyperextension of the metacarpophalangeal joint, but in neither of these did the hyperextension detract significantly from the satisfactory result of tendon transfer (Fig. 3). Delayed union at the site of osteotomy occurred in one patient. There was one report of a stitch abscess in the thenar incision.

DISCUSSION

At this hospital the preferred motor tendons for transfer in the restoration of opposition have been the flexor sublimis of the ring finger, employed in sixty-four procedures, and that of the long finger, employed in twenty-nine procedures. There was no apparent difference in the operative results (Table I). When these tendons are not strong enough for transfer, other motors are employed. Thus, the flexor carpi ulnaris was used in four instances, and the palmaris longus in one instance, prolonged by free tendon grafts from the extensor tendon of the fourth toe. The results were rated for four of these five procedures; one was found to be good, one fair, and two poor. The flexor profundus of the little finger was used as the motor in three instances, with results of good or better in each. To preserve flexor power in the donor digit when the profundus tendon was transplanted the residual distal portion of the tendon was sutured to the adjacent profundus tendon of the ring finger in the palm.

The Thompson pulley was used in ninety-four of the 103 operations that were rated. The results were good or excellent in seventy-two, fair in seven, and poor or failures in fifteen. In sixty-four instances where this pulley was used in combination with the dual insertion, as originally described, there were good or better results in fifty, fair results in four, and poor results or failures in ten. The second most common method of insertion of the transplanted tendon was suture of the transplant to the tendon of the abductor pollicis brevis muscle and to the expansion of the extensor pollicis longus tendon at the joint capsule. This procedure was

FIG. 4

A method of postoperative protection, easy to apply, permitting use of the thumb.

employed in twenty-four of the thumbs with known end results; the results in twenty-one were good or better, and only three were rated *poor* or *failures*. Insertion on the metacarpal neck alone was employed in twelve thumbs; six were rated *good* or better, three *fair*, and three *poor* or *failures*. Insertion to the base of the proximal phalanx alone was used in three instances, with two results rated *good* and one *fair*. The Bunnell pulley was employed in ten instances, and seven of these were rated; in five the results were good or better, one result was fair, and one was a failure.

In the analysis of the seventeen poor results or failures, it was found that there were eight instances in which there was such extensive paralysis that little success could be expected; there was one patient who fell on her hand eight weeks after operation after good function of the transplant had been noted; there was one patient in whom a contracture of the web space had not been corrected; and there was one Steindler procedure. In the remaining six instances failure was thought to be a consequence of utilization of a weak motor, faulty technique, or insufficient postoperative protection. We have, as a rule, practiced postoperative protection in a position of opposition for six weeks, followed by the use of a night splint. The tape dressing shown in Figure 4 may be used immediately after the operation and for the subsequent six weeks. Later a plastic opponens splint is used at night. Active motion is usually permitted after three weeks.

In their study of paralytic thumb deformities, Goldner and Irwin listed certain prerequisites essential to the successful restoration of thumb opposition. These included the presence of a strong flexor pollicis longus, abductor pollicis longus, and extensor pollicis longus. Operation to restore opposition was not recommended if the patient was below the age of twelve or fourteen years. Postponement of the operation was advised until the patient was considered old enough to

FIG. 5-A

FIG. 5-B

B. M., a man, thirty-eight years old, who had had poliomyelitis at the age of three years. The preoperative deformity and the inability to use the thumb when making a fist are shown. The extensor pollicis longus was rated *fair*.

FIG. 5-C

FIG. 5-D

The result is shown after the Thompson procedure with osteotomy. Note the ability to oppose and incorporate the thumb in a grip.

participate in muscle re-education and until skeletal maturity had been approached. The results in this series demonstrate that success is frequently achieved despite the absence of these listed prerequisites. In fact, our best results have been in young children. Complete muscle ratings in fifty-five of our procedures with good or excellent results are considered thoroughly reliable. Ratings of *fair* or less were given to the abductor pollicis longus in thirty-six instances, to the extensor pollicis longus in twenty instances, and to the flexor pollicis longus in nine instances. In fifteen instances, ratings of *fair* or less were assigned to both the abductor pollicis longus and the extensor, and in four instances all three long thenar muscles were similarly rated (Figs. 5-A through 8). Complete and reliable muscle ratings before operation were available for seventy-one patients (Table I). Involvement of the first dorsal interosseus or adductor pollicis rarely deterred from the restoration of opposition. The first dorsal interosseus was rated *fair* or less in thirty six patients in whom good or excellent results were obtained; the adductor pollicis was rated *fair* or less in twenty-one patients with good or excellent results.

FIG. 6-A

FIG. 6-B

Fig. 6-A: E. M., a man, thirty-five years old, who had had poliomyelitis at the age of four years. The typical deformity and the opposition paralysis of the left hand before operation are shown. The abductor pollicis longus and the extensor pollicis longus were rated as *fair*.

Fig. 6-B: The result is shown after the Thompson procedure with osteotomy.

However, both the first dorsal interosseus and the abductor pollicis longus were rated *fair* or less in five patients in whom fair results were obtained and in ten patients with poor results (failures).

Thirty-six operations for the restoration of opposition were performed on children whose ages ranged from four to twelve years and for whom there was an average of three years after the onset of poliomyelitis. The end results are known in twenty-nine of these instances, with twenty-six rated as *good* or *excellent*, two as *fair*, and one as *poor*. Some of the children are known to have achieved considerable skill in hobbies and sports requiring the use of the involved hand, such as ceramics, table tennis, archery, and playing the piano. It appears unnecessary, in our experience, to deny the patient a more useful hand purely on the grounds of age. Delaying the operation merely increases the possibility of deformity and may impair the final result.

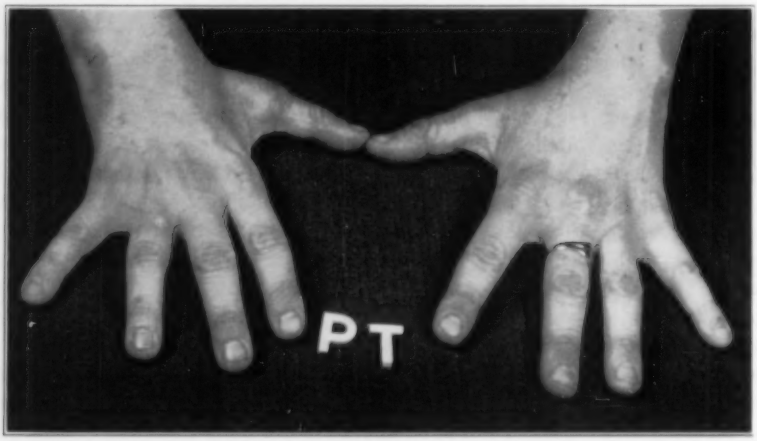


FIG. 7-A

FIG. 7-B

Figs. 7-A and 7-B: P. T., a boy, four years old, who had had poliomyelitis at the age of three years. The opposition of the thumb of the right hand is shown after operation using the Bunnell pulley and the Riordan insertion. The extensor pollicis longus was rated as better than *poor*.

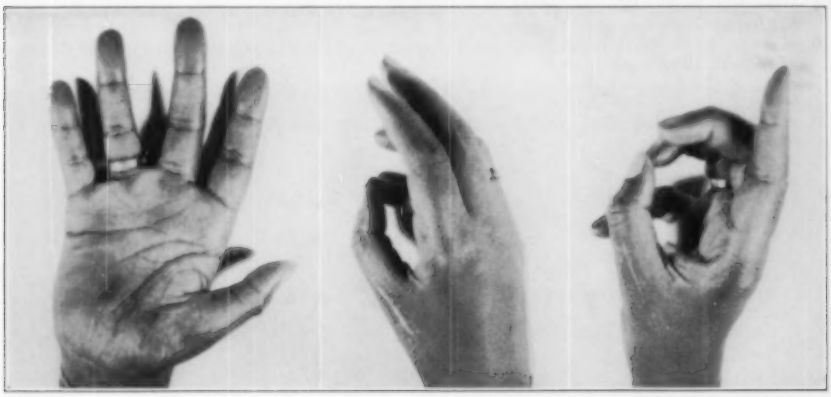


FIG. 8

A. J., a woman, twenty-two years old, who had had poliomyelitis at the age of two years. The result is shown after the Thompson procedure. The abductor pollicis longus was rated as better than *fair*.

It is worth noting that restoration of opposition is frequently only one step in the rehabilitation of the upper extremity as a whole. This necessitates a carefully planned approach. There is little point, for example, in providing an opposable thumb in a hand whose function is markedly restricted because of coexistent paralysis of all the intrinsic muscles or of all the muscles of the wrist, elbow, or shoulder. Other surgical procedures performed on the patients in this series include five wrist fusions, six Steindler elbow flexorplasties, seven shoulder fusions, one pectoralis major transplant, and many other tendon transplants about the wrist and hand. As a rule, in the restoration of function to the upper extremity, we have preferred to begin reconstruction in the hand because extensive reconstructive procedures on the rest of the extremity are not worthwhile unless there is useful function of the hand.

CONCLUSIONS

The restoration of opposition is feasible by means of several operative

approaches. Among them the Thompson procedure offers a relatively simple yet effective method. If failure occurs it can seldom be attributed to a fault of the particular method employed; it is much more often caused by the selection of an inadequate motor tendon or its insertion under insufficient tension.

Residual power and function of the hand and the relationship of the hand to the extremity as a whole must be carefully appraised before attempting to restore opposition of the thumb.

If contracture of the thumb has occurred, this deformity should be corrected prior to (or at the time of) tendon transfer.

The restoration of opposition of the thumb in children should not be delayed because of age or skeletal immaturity.

REFERENCES

1. Bunnell, Sterling: Surgery of the Hand, pp. 576–584. Ed. 3. Philadelphia, J. B. Lippincott Co., 1956.
2. Duchenne, G. B. A.: Physiology of Motion Demonstrated by Means of Electrical Stimulation and Clinical Observation and Applied to the Study of Paralysis and Deformities, pp. 162–181. Translated and edited by E. B. Kaplan. Philadelphia, W. B. Saunders Co., 1959.
3. Goldner, J. L., and Irwin, C. E.: An Analysis of Paralytic Thumb Deformities. J. Bone and Joint Surg., **32-A:** 627–639, July 1950.
4. Grant, J. C. B.: A Method of Anatomy, Descriptive and Deductive, pp. 149–150. Baltimore, The Williams and Wilkins Co., 1952.
5. Grinker, R. R.: Diseases of the Nervous System. *In* Practice of Medicine. Vol. 9, p. 250. Edited by Frederick Tice. Hagerstown, W. F. Prior Co., 1937.
6. Kaplan, E. B.: Anatomical Problems of Opposition of the Thumb. Bull. Hosp. Joint Diseases, **15:** 56–59, 1954.
7. Last, R. J.: Anatomy, Regional and Applied. Boston, Little, Brown and Co., 1954.
8. Markee, J. R.: The Anatomy of the Hand. *In* The American Academy of Orthopaedic Surgeons, Instructional Course Lectures. Vol. 14, pp. 149–162. Ann Arbor, J. W. Edwards, 1957.
9. McGregor, A. L.: A Synopsis of Surgical Anatomy, p. 171. Baltimore, The Williams and Wilkins Co., 1957.
10. Ney, K. W.: A Tendon Transplant for Intrinsic Hand Muscle Paralysis. Surg., Gynec., and Obstet., **33:** 342–348, 1921.
11. Riordan, D. C.: Surgery of the Paralytic Hand. *In* The American Academy of Orthopaedic Surgeons, Instructional Course Lectures. Vol. 16, pp. 79–90. St. Louis, The C. V. Mosby Co., 1959.
12. Royle, N. D.: Operation for Paralysis of Intrinsic Muscles of the Thumb. J. Am. Med. Assn., **111:** 612–613, 1938.
13. Steindler, Arthur: Flexor Plasty of the Thumb in Thenar Palsy. Surg., Gynec., and Obstet., **50:** 1005–1007, 1930.
14. Steindler, Arthur: Kinesiology of the Human Body Under Normal and Pathological Conditions. Springfield, Charles C. Thomas, 1955.
15. Thompson, T. C.: A Modified Operation for Opponens Paralysis. J. Bone and Joint Surg., **24:** 632–640, July 1942.

DISCUSSION

Dr. Leo Mayer New York, N. Y.: This paper is an impressive record of good results: seventy out of ninety-nine, or almost 80 per cent, were good. When we realize that most of the operations were performed by the Resident Staff, the figures indicate that the operation must be a reliable procedure. This is to me all the more remarkable since the technique was developed in direct opposition to the views of our acknowledged master of hand surgery—Sterling Bunnell. He came out emphatically against the Thompson pulley, but the objective record shows that even Bunnell could sometimes be wrong. Actually, the line of traction secured by the Thompson pulley differs only by a few degrees with that of the Bunnell pulley. Both pulleys are effective, and satisfactory opposition can be secured if the other details of the operation are carried out. I, myself, have followed the Bunnell method ever since Bunnell himself demonstrated it to me on the cadaver. In my forty-odd cases I have also secured about 80 per cent of good results, and, like the authors of this paper, I have tried to analyze my failures. The causes were the following:

First, inadequate correction of the abduction, external-rotation contracture. Having recognized this fault, I corrected the contracture by thorough capsulotomy of the carpometacarpal-joint ligaments. Only once did I have to osteotomize the first metacarpal, but I recognize the osteotomy as a valid method of correction.

Second, inadequate fixation of the tendon. If drawn through a drill hole, the tendon must be thoroughly scarified, so as to remove the superficial gliding cells and thus secure firm union to the

(Continued on page 1039)

Transposition of the Compressed Spinal Cord in Kyphoscoliotic Patients with Neurological Deficit

With Special Reference to the Vascular Supply of the Cord*

BY RICHARD C. SCHNEIDER, M.D., ANN ARBOR, MICHIGAN

From the Correlative Neurosurgical Research Laboratory,
University of Michigan Hospital and Medical School, Ann Arbor

Transposition of the spinal cord is the surgical procedure in which the spinal cord is relocated in a new bed to overcome a neurological deficit which is caused by compression of the spinal cord as the result of severe scoliotic and kyphotic deformities.

Transplantation is the term found in the literature for this procedure. This term was proposed by Hyndman in his original article on this subject and Love has continued to use it, although he observed that transplantation is defined as grafting of tissues taken from the same body or another body—so strictly speaking, this is not a transplantation of the spinal cord. Hence, transposition would seem to be a better term.

FIG. 1-A

FIG. 1-B

Fig. 1-A: Case 1. Lateral roentgenogram of the thoracolumbar spine shows a marked gibbus at the twelfth thoracic vertebra.

Fig. 1-B: The anteroposterior roentgenogram demonstrates the degree of vertebral angulation (arrow). There is an associated right twelfth thoracic hemivertebra and a fifth lumbar spina bifida occulta.

* This work was carried out under United States Public Health Service Grant B-1442(C1).

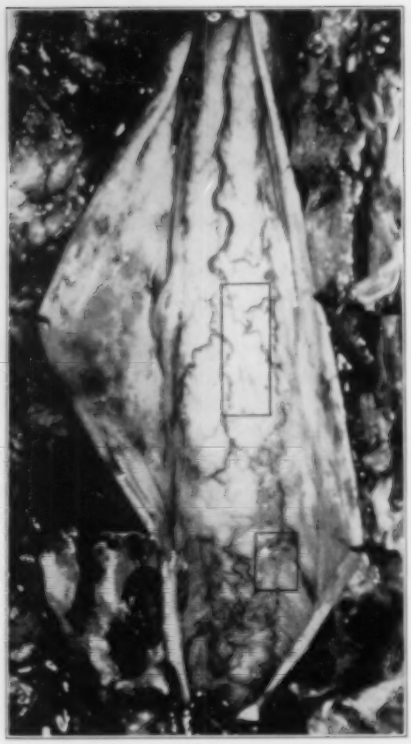


FIG. 1-C

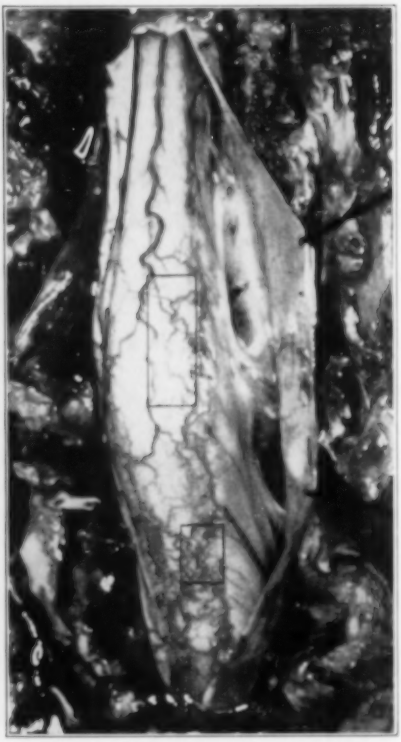


FIG. 1-D

Fig. 1-C: The thoracolumbar spinal cord is visualized at the operative site just after opening the dura and prior to decompression. The cord was edematous and tense, and the blood vessels on its surface were definitely less filled with blood due to stretching caused by the marked angulation. Compare designated zones with corresponding areas in Fig. 1-D.

Fig. 1-D: The same operative field seen in Fig. 1-C is shown at the same photographic parameters following decompression of the spinal cord. There is a definite increase in vascularity and collateral circulation on the dorsal and lateral surface of the spinal cord. In the lower zone the appearance supports the statement by Gillilan that "the so-called posterior spinal arteries are in fact two posterior plexiform channels running longitudinally on a line with the entrance of the rootlets of the posterior spinal nerves".

Three cases of congenital scoliosis treated by transposition of the spinal cord are presented here. They will form the basis for a discussion of the problems involved in such procedures.

CASE 1. M. R., a ten-year-old boy with severe thoracolumbar kyphoscoliosis, had fallen at 6 P.M. on March 16, 1956, and arrived at University Hospital at 2:20 A.M. the following day. After injury complete areflexic paraplegia had developed, with a sensory level at the second lumbar dermatome; nevertheless, his pre-existing spinal deformity was unchanged. There were no extensor plantar reflexes. Spine roentgenograms showed a marked thoracolumbar kyphoscoliotic deformity with a convexity to the right and the apex of the curve at the twelfth thoracic level, where there was a right-sided hemivertebra (Figs. 1-A and 1-B). The posterior neural arches were not visualized in the upper lumbar regions, and there was spina bifida occulta of the fifth vertebra. A lumbar puncture was performed and an incomplete block was found on the jugular vein-compression test. No cerebrospinal fluid was removed. Pantopaque was injected, and on myelography, there was a complete block at the first lumbar vertebral level. A laminectomy was performed at the twelfth thoracic, first lumbar, second lumbar, and third lumbar vertebrae, revealing the dura to be compressed extradurally by the sharp bony angulation. The dura was opened, demonstrating a swollen, pale, angulated spinal cord with the conus medullaris extending downward to the third lumbar vertebral level (Fig. 1-C). The articular facets of the twelfth thoracic, first and second lumbar vertebrae had to be removed bilaterally to accomplish spinal-cord decompression. It was necessary to chisel away carefully the posterior half of the first lumbar vertebral body since it was jutting posteriorly against the dura and the spinal cord. An intradural and extradural decom-

pression of the nerve roots in this region was performed without sectioning any of the roots. The intervertebral discs were removed at the twelfth thoracic-first lumbar and first lumbar-second lumbar interspaces. After completion of the operation, the arachnoidal sac pulsated; the collateral circulation of the decompressed spinal cord appeared to be considerably improved (Fig. 1-D); and the spinal cord was straightened to some degree. The wound was closed since the patient was in no condition to undergo an extensive spine fusion.

A week after operation the patient had some recovery of bladder and bowel sensation but he could not move his lower extremities. By the second week he was able to void spontaneously. Six months later he had a normal sensory examination, fair motor power in the left lower extremity, marked weakness in the right lower extremity, bilateral extensor plantar reflexes, and ankle clonus. Roentgenograms of the thoracolumbar spine demonstrated an increase in the gibbus. A body cast with turnbuckles was applied to hyperextend the spine.

On October 21, 1956, Dr. John Hayes and Dr. Marian DeWeese performed a left costotransversectomy through a left flank incision with excision of part of the eleventh rib. Several small segmental branches of the aorta were identified and ligated. The lateral and anterior portions of the bodies of the tenth, eleventh, and twelfth thoracic and first and second lumbar vertebrae were denuded of soft-tissue attachments. The left crux of the diaphragm was reflected superiorly and the quadratus lumborum muscle was reflected inferiorly. The lateral and anterior portions of the tenth, eleventh, and twelfth thoracic and first and second lumbar vertebral bodies were denuded of cortical bone to procure a raw bleeding bed of cancellous bone. The eleventh rib and irradiated bank bone were firmly fixed in place in this bed. The various layers of the wound were reapproximated. A turnbuckle cast was applied and the back forced into hyperextension. After rehabilitation measures were instituted, he was sent home on a Stryker frame.

By March 4, 1957, about a year after the first operation, the child was able to walk with the aid of a Taylor back brace and single right double upright brace. He was progressing rapidly with stair climbing and getting in and out of a chair. A year later, roentgenograms made at another hospital demonstrated complete absorption of the wedge-shaped twelfth thoracic vertebral body with resulting spinal instability. It was reported that an onlay tibial graft was applied laterally along the bodies of the vertebrae to accomplish stabilization. His neurological status was said to be good with sufficient strength in his legs to permit him to walk.

Comment: The patient had an initial kyphoscoliotic deformity with chronic cord compression. Sudden severe neurological deficit developed with immediate complete areflexic paraplegia following an episode of acute trauma. The indications for operation were a complete block on myelographic examination and the increase in neurological deficit. In this case, decompression of the spinal cord was attained by chiseling away bone anterior and lateral to the spinal cord and by incising the dura mater. The lesion had its maximum angulation at the twelfth thoracic-first lumbar vertebral level. No nerve roots were sacrificed in transposing the cord into a new bed and the patient continued to regain motor and sensory function. His major problem has been the further stabilization of the spine in order to prevent progression of the deformity. In spite of the attempt to preserve as much bone as possible at the time of the initial operation, the first spine fusion was not successful, perhaps due to lack of a bone bed and interference with vascular supply to the bones at the fusion site.

Case 2: R. S., a seventeen-year-old boy with congenital kyphoscoliosis of the thoracic spine, was admitted to University Hospital on August 7, 1957, complaining of progressive curvature of the spine and increasing weakness and spasticity in his lower extremities for seven months. He had no loss of bowel or bladder function. His father had had a similar spine deformity. At the time of the initial examination, the patient's marked kyphoscoliosis of the thoracic spine with its concavity to the left and the associated thoracic-cage deformity were noted. In the lower extremities he had marked bilateral paresis and spasticity, which were more marked on the right side, and bilateral fasciculations in the thigh muscles. He had a definite level of hypalgesia from the eleventh thoracic to the third sacral dermatomes and a milder degree of hypalgesia between the sixth and tenth thoracic dermatomes. Position sensation was intact, except for some diminution in the right foot. He had incoordination on the right heel-to-knee test and the Romberg test was positive with a tendency to fall backward and to the right. His gait was ataxic but this was paraparetic rather than cerebellar in pattern. He had sustained ankle clonus and bilateral extensor plantar reflexes.

Roentgenographic examination was made of the entire spine. It revealed only five cervical

vertebrae on the lateral view. There was extensive kyphoscoliosis with extreme angulation to the left at the sixth and seventh thoracic levels (Fig. 2-A). This deformity seemed to be secondary to a twelfth thoracic hemivertebra. Due to the extreme abnormality, the exact structural components could not be discerned with accuracy. He had a marked crowding of the right ribs with a large gap in the rib cage existing on the left due to congenital absence of the sixth left rib (Fig. 2-B). His lumbar-spine roentgenograms showed only a first sacral spina bifida occulta. The chest roentgenograms showed no pulmonary disease.

FIG. 2-A

Case 2. Lateral roentgenogram of the thoracic spine exhibits the severe angulation at the sixth thoracic-seventh thoracic level.

On August 12, 1957, operation was performed, exposing the second thoracic through the tenth thoracic spinous processes and laminae. A laminectomy was done from the fourth thoracic through the ninth thoracic levels. There was impingement of the right nerve roots on the articular processes of the fourth through the ninth thoracic vertebrae. The thoracic cord at the fifth thoracic-sixth thoracic level was found to be doubly arched and angulated to 90 degrees. At this site, the spinal cord was severely flattened in the anteroposterior plane and measured 1.5 centimeters in width, whereas at the seventh through the ninth thoracic levels it measured two centimeters in width. Initially, pulsation occurred only at the fourth and fifth thoracic levels. The left pleural cavity was accidentally entered at the seventh thoracic level while endeavoring to place a retractor. The pleural tear was readily closed with interrupted black silk sutures, a muscle plug, and an oxycel pack. The underlying left ribs, the transverse processes, the articular processes, and the right vertebral bodies from the fourth to the seventh thoracic vertebrae were painstakingly chiseled away from under the spinal cord for a distance of twelve centimeters. The vertebral bodies, the ligamenta flava, the rib articulations, transverse processes, and other structures which are usually readily identified were markedly abnormal. The right fifth and sixth thoracic-nerve roots, which were enmeshed in fibrous tissue, were clipped, ligated extradurally, and sectioned. The right posterior root of the seventh cervical nerve was found to extend circuitously ending blindly in mid-line fibrous tissue under the spinal cord. This was excised. The left posterior roots of the fifth and sixth cervical nerves and the posterior roots of the seventh and eighth cervical nerves were closely clumped in pairs, and the two groups were widely separated from each other. The interspaces and their intervertebral discs were poorly defined. A herniated intervertebral disc was removed from beneath the spinal cord at the fifth thoracic-sixth thoracic interspace. The dura mater was bound

down in many areas to the vertebral bodies anteriorly, and to the ribs laterally by fibrous tissue which had to be carefully dissected away. The dura and spinal cord were released from tension and transposed anteriorly and laterally toward the right side into a new bed extending from the fourth to the eighth thoracic levels. The dura pulsated moderately at the close of the operation. At no time during the procedure was the dura opened.

Twenty-four hours postoperatively, the patient was able to move his lower extremities, the left more than the right. At seventy-two hours after operation he was unable to move any portion of either lower extremity; his position and motion sensations were lost and he retained only touch bilaterally. After another forty-eight hours had elapsed, he began to move both lower extremities voluntarily, although he also had infrequent involuntary movements. Postoperatively, roentgenograms showed the changes incident to operation (Fig. 2-C). By September 10, 1957, he was discharged, walking with two canes.

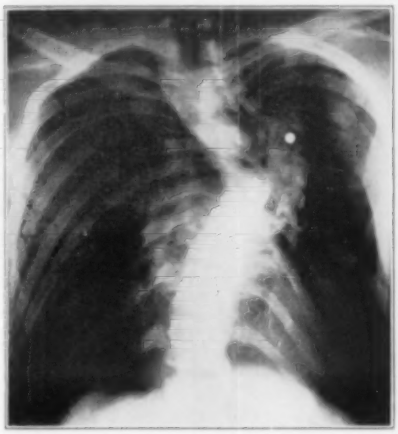


FIG. 2-B

FIG. 2-C

Fig. 2-B: Anteroposterior roentgenogram shows the marked kyphoscoliosis with its maximum angulation and convexity to the left designated at the sixth thoracic level by the marker. There is a congenital absence of the left sixth rib. Note the crowding of ribs and distortion of the thoracic cage. The pantopaque column is blocked at the seventh thoracic-eighth thoracic interspace.

Fig. 2-C: The postoperative anteroposterior roentgenogram shows the wire sutures used for closure of the muscle layer. The heads of the fifth, sixth, and seventh ribs, part of the articulations and transverse processes of the fifth, sixth, and seventh thoracic vertebrae have been removed to permit right lateral transposition of the spinal cord into its new bed (Fig. 6).

A final follow-up note on June 18, 1958, was made stating that the patient was neurologically negative with the exception of symmetrically hyperactive patellar reflexes. The patient stated in a letter on April 15, 1959, that he was able to play baseball without difficulty and that since his spine was stable, his orthopaedic surgeon had found no need for the use of a brace. He reported that he was getting along very nicely.

Comment: This patient displayed the problem of chronic compression of the mid-thoracic cord by congenital kyphoscoliosis. At operation the dura was not incised; the right fifth and sixth thoracic-nerve roots were ligated and transected extradurally. Decompression of the thoracic spinal cord was accomplished by transposition to an anteromedial position. Since the dura was not opened at operation, the surgeon suffered several uncomfortable days during which progressive neurological deficit developed with complete loss of motor power on the third postoperative day; the sensation of touch alone remained intact. Reopening of the wound and incision of the dura was seriously considered on more than one occasion during this interval. This was never done, but good surgical judgment would have favored reopening of the wound and dural incision. Two years after operation, roentgenographic and clinical examination of the spine demonstrated that no spine fusion was necessary for the purpose of stabilization.

CASE 3: G. H., a seventeen-year-old boy, was admitted to University Hospital on May 9,

1953, with the chief complaint of having had difficulty walking for eleven months. Although he had had a drooping of his left shoulder and a hump deformity of his back all his life, his parents had observed that it had become more marked during the two years prior to this hospitalization. During the summer of 1952 he had noted decreased ability to pedal his bicycle, had had some difficulty in walking due to awkwardness of his feet, and had a tendency to fall toward the left side. At the time of admission to the hospital, these symptoms had progressed to the point where he could walk only with support, and some difficulty in initiating urination had developed. There had never been any history of poliomyelitis or tuberculosis.

The patient had a faulty memory but his judgment was fair. He had a kyphoscoliosis in the region of the second through the seventh thoracic vertebrae with the apex of the deformity directed toward the left side. There was marked weakness in his legs, particularly in the quadriceps muscles

FIG. 3-A

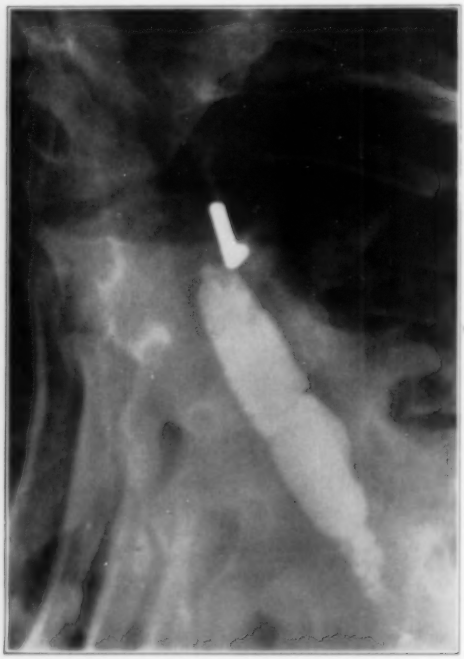


FIG. 3-B

Fig. 3-A: Case 3. Roentgenogram of the cervicothoracic area shows the marked kyphoscoliosis with the apex at the right third thoracic vertebral level.

Fig. 3-B. The myelogram shows a complete blockage of the pantopaque column at the fourth thoracic level. The characteristic crowding of the heads of the ribs along the concave portion of the spinal curvature may be seen. The contralateral ribs on the convexity of the spinal curve always have a compensatory sloped upward curve as is seen in the left side of the chest.

bilaterally but there was no atrophy or increased tonus. He could move his toes and his feet in dorsiflexion and plantar flexion. There was a loss of all sensory modalities up to the third thoracic dermatome on the left and to the fourth thoracic dermatome on the right. He had hyperactive patellar and Achilles reflexes with extensor plantar reflexes.

The roentgenograms of the cervicothoracic spine exhibited a very severe kyphoscoliosis. The apex of the kyphos was at the third thoracic vertebra with angulation of the spine almost to a right angle (Fig. 3-A). Two neurological consultants believed that there was cord impairment to the fourth cervical level, while three others thought that its most cephalad point was at the second thoracic vertebra. This indicated the marked variability in findings which were probably related to the impaired blood supply. The blood supply was presumably marginal with no reserve. On May 12, 1953, a lumbar puncture was made and since there was a complete block on the manometric test, no cerebrospinal fluid was removed for protein determination, but pantopaque was injected. At myelography a complete blockage of the flow of the radiopaque medium was found at the fourth thoracic level (Fig. 3-B). Immediately following the procedure, a complete laminectomy was performed of the first, second, third, and fourth thoracic vertebrae. In some areas, the kyphoscoliotic deformity was so marked that it was difficult to identify the posterior margin of

the vertebra. The dura, which was stretched tautly on the posterior surface of the vertebral bodies, was opened, leaving the arachnoid intact. The spinal cord had the appearance of a stretched white tendon. It was the consensus at the operation that the prognosis for recovery was extremely grave, regardless of the type of operative decompression that was selected. Although most of the spinal cord was atrophic, it was believed that an attempt should be made to transpose it to a new bed. The right articular facets of the first, second, and third thoracic vertebrae were rongueured away. The second and third thoracic-nerve roots were ligated extradurally and sacrificed bilaterally. This permitted excision of three-quarters of an inch of the posterior aspect of the first, second, and third thoracic vertebral bodies, forming a trough into which the spinal cord could be transposed. Although the spinal cord was decompressed, the arachnoid only pulsated on bilateral jugular-vein compression. The arachnoid and the denticulate ligaments were left intact but the dura was slit both longitudinally and transversely to prevent compression of the cord. The wound was closed in layers.

Three days after operation, the patient's indwelling catheter could be removed because he had regained bladder function. A month after operation, the patient was discharged with a flaccid paraplegia, hypalgesia to the level of the fourth thoracic dermatome, and recovery of deep pain and position sensations. He first began moving his lower extremities six weeks after the surgical procedure.

The patient was last seen five years after operation. At that time he was walking with a mildly spastic paraparetic gait with generalized hyperreflexia, extensor plantar reflexes, and a hypalgesia to the third thoracic level. He had been working daily earning his living as a movie projectionist for a large manufacturing company. Roentgenograms of the cervicothoracic spine at this time showed no further progression of his deformity.

Comment: The appearance of the atrophic narrowed spinal cord at operation definitely gave the impression that the operative procedure would be futile. The decompression of the cord in this case was accomplished by section of the second and third thoracic-nerve roots bilaterally with transposition of the cord anterolaterally. Although recovery was not complete, the degree of functional return that the patient attained was most gratifying.

DISCUSSION

Kyphoscoliosis with spinal-cord compression and neurological disability may occur as complications of Pott's disease, certain neoplasms, syringomyelia, and less frequently as a complication of idiopathic scoliosis. The first use of costotransversectomy as a surgical measure to decompress the cord in patients with Pott's disease has been attributed to Ménard in 1900. Subsequently, many such operations were performed and the results reported in the literature[4,21]. However, surgical decompression of patients with scoliosis has been carried out much less frequently, because the compressing mass in these instances is solid bone whereas in Pott's disease, the mere removal of soft granulation tissue and drainage of an abscess have sufficed to accomplish symptomatic relief.

In 1949, McKenzie and Dewar described five patients who had spinal-cord compression associated with idiopathic kyphoscoliosis. At that time, they reviewed the literature and found an additional thirty-seven reported cases which had been similarly treated by decompressive laminectomy with or without opening of the dura. In one of their cases, two tight nerve roots were sectioned, and in one instance an aberrant or congenital band which was constricting the dura was severed. In the entire series of forty-two cases in the literature, fifteen patients did well, the dura having been left open in thirteen of them. Recovery was complete in five of these patients. In eight cases, there were no postoperative complaints by the patient despite residual spasticity and these patients were able to walk.

McKenzie and Dewar believed that "The benefit gained from operation was clearly due to release of tension on the spinal cord by opening the dural sac".

Hyndman, in 1947, recorded the first case of transplantation (transposition) of the spinal cord in idiopathic kyphoscoliosis with chronic spinal-cord compres-

sion. In addition to laminectomy, he removed the pedicles and transverse processes of the vertebrae and the heads of the fourth through the seventh ribs on the concave side of the deformity. Four pairs of nerve roots (third through sixth thoracic) were divided extradurally and the cord was transplanted with good functional recovery. Hyndman agreed that such an operative approach is unnecessary in Pott's disease because the soft-tissue lesion is more readily removed. With regard to transplantation (transposition) of the spinal cord, he stated that "If one or two pairs of neighboring nerve roots are ligated and cut extradurally, retraction of the cord and chiseling of the protruding vertebral body is greatly simplified. However, one hesitates to disturb ever so little the blood supply to the damaged cord segment by severing the arteries that accompany nerve roots".

Love and Erb [12] applied the operation of transplantation (transposition) of the spinal cord to the relief of paraplegia in cases of Pott's disease. Subsequently, Love [12] in 1956 performed the operation on eleven patients, only two of whom had idiopathic scoliosis. He stated that "Since this operation is usually performed for lesions involving the thoracic portion of the spinal cord, there is no serious impairment after the rhizotomy. The neurosurgeon would hesitate to divide a lumbar or sacral root. Likewise he would not want to divide one of the roots from the fifth cervical to the first thoracic root, inclusive, because these roots innervate the extremities, and it is the function of the extremities that he is trying to preserve or restore".

It is rather surprising that patients were treated by transplantation (transposition) of the spinal cord without more attention having been directed toward the vascular supply of the spinal cord. The latter is somewhat variable but it might be well to consider its general pattern as mapped out in the extensive studies of many workers in order to select the most effective and proper surgical approach to the spinal-cord problems under consideration here [2,9,11,18,19,20,23,24,25].

In a discussion of the embryonic development of the spinal cord, Evans, Gillilan [6,7], and Mall were impressed by the normal variability in the arteries which finally become the permanent channels for the nutrition of the spinal cord. In the cervical portion of the spine there are paired arteries which arise from the vertebral arteries and unite in the mid-line to form a vessel which runs anterior to the spinal cord as the anterior spinal artery and extends caudad to the fourth thoracic spinal-cord segment (Fig. 4) [8]. Bolton stated that there is a zone of poor collateral circulation at the first to third thoracic-cord segments. Zülch believed that this critical area is at the fourth thoracic segment. Below this level there is the anterior mid-line vessel which has been designated by Yoss as the anterior medial spinal artery. Segmental intercostal arterial branches are given off from the aorta to supply the thoracic segments down to the first lumbar segment. Adamkiewicz believed that one of these intercostal rami was routinely larger than all of the remainder and named it the *arteria radicularis anterior magna*. This vessel, designated by Mettler and associates as the great ventral radicular artery, enters the spinal cord somewhere between the eighth thoracic and the fourth lumbar spinal-cord segments. Bolton and Zülch believed that this vessel enters at the ninth thoracic segment. Gillilan designated this vessel, one of the largest of the medullary arteries, as the great anterior medullary artery which enters most often at the first or second lumbar segments on the left side. In any event, the direction of blood flow is upward to the fourth thoracic segment and caudad to the first lumbar segment, where there is another zone of poor collateral vascular supply.

The dorsal and ventral radicular arteries which accompany the posterior and anterior nerve roots, respectively, are given off segmentally from the intercostal

or lateral spinal arteries. They tend to unite with the posterior and anterior spinal arteries directly and are linked segmentally about the periphery of the spinal cord as the arteriae coronae (Fig. 5). According to Suh and Alexander the completely efficient radicular arteries are present at the sixth cervical, tenth thoracic, and first lumbar neural segments.

It should be recalled that there is a disproportionately more rapid growth of the spine than of the spinal cord, resulting in the shift of neural segments more cephalad than the corresponding vertebrae. Thus, the two critical zones for the blood supply to the spinal cord are located so that the fourth thoracic neural segment lies over the third thoracic vertebral body and the first lumbar neural segment is located over the tenth thoracic vertebral body.

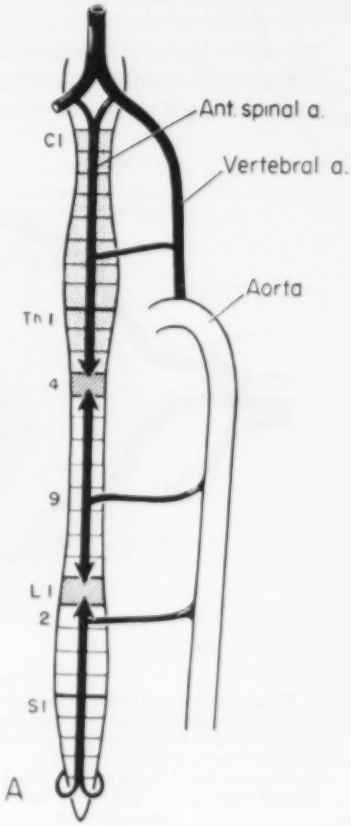


Fig. 4

Fig. 4: "The diagram shows origins of anterior spinal artery from vertebral artery bilaterally. Anterior spinal artery supplies anterior two-thirds of cervical spinal cord and uppermost thoracic segments to T4 level. Blood flow is caudal. Collateral supply is poor in region of T4 neural segment, so that hypoxia may cause infarction here in distribution of the anterior sulcal arteries with central cord destruction. The remainder of arterial supply for thoracic cord from T4 to L1 is by intercostal branches from the aorta. The major one, the great ventral radicular artery, enters at T9 segment in this diagram. Another zone of poor collateral supply is at L1 dermatome." (Reproduced from Bing's Local Diagnosis in Neurological Diseases, p. 478. By Webb Haymaker. Ed. 14. St. Louis, The C. V. Mosby Co., 1956.)

Hyndman first distinguished between anterior and lateral transplantation (transposition) of the spinal cord in kyphoscoliotic patients with compression of the spinal cord caused by bone. In his paper, he described an anterior transplantation of the spinal cord in a case of Pott's disease; two nerve roots were cut and the posterior surface of the vertebral bodies were chiseled away, dropping the cord into a new bed. In a second case, one of idiopathic scoliosis, lateral transplantation of the cord was accomplished by removal of the pedicles, the heads of the ribs, parts of the vertebral bodies and, after sectioning of several nerve roots, the dura was left open.

If the relationship between the collateral blood supply of the cord and the possible impairment of cord function after transposition are considered, it may be well to define what is meant from a practical standpoint by the terms anterior and lateral transposition.

The author would suggest that the term *anterior transposition* be confined merely to the process of chiseling away the vertebral bodies and permitting the cord to seek a new bed without sacrifice of any of the spinal-nerve roots with their associated blood vessels (Fig. 6, insert). The term *lateral transposition* of the cord may then be used for the procedures in which the pedicles, heads of the ribs, vertebral bodies, and other structures are removed, and rhizotomy is performed as well. The latter term should convey the impression that a more serious and extensive procedure had been carried out (Fig. 6).

Therefore, any kyphoscoliotic lesion with its apex at the third or fourth

thoracic vertebra or at the tenth or eleventh thoracic vertebra should be treated, if possible, without rhizotomy in order to preserve the radicular arteries and avoid vascular insufficiency to the spinal cord. Under these circumstances chiseling away the bone anterior to the cord with *anterior transposition* should be attempted to accomplish anterior decompression.

From the level of the fifth through the ninth thoracic vertebrae, it should be safe to perform *lateral transposition* of the spinal cord. Theoretically, in this region, there should be no interference with the vascular supply to the cord itself as the result of section of the nerve roots.

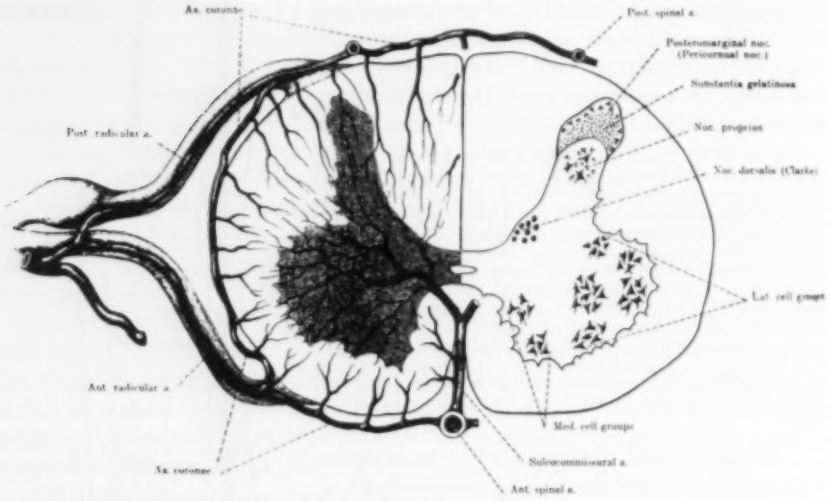


FIG. 5

This cross section of the spinal cord demonstrates the posterior and anterior radicular arteries joining the posterior and anterior spinal arteries respectively. The radicular vessels themselves are joined along the periphery of the cord by the arteriae coronae. The latter vessels complete the circular vascular supply about the periphery of the cord by also joining the two posterior spinal arteries on the dorsum of the spinal cord. (Reproduced from Bing's Local Diagnosis in Neurological Diseases, p. 478. By Webb Haymaker. Ed. 14. St. Louis, The C. V. Mosby Co., 1956.)

From a practical standpoint, the three cases presented in this paper must be examined with these factors in mind.

In Case 1 the apex of the deformity was at the twelfth thoracic and first lumbar vertebrae, and decompression was performed anteriorly by chiseling away bone without rhizotomy. Presumably, nerve roots could have been transected safely at this site.

In Case 2 the point of bony angulation was greatest at the fifth and sixth thoracic vertebral level. Bone was chiseled away laterally and anteriorly, and a rhizotomy was performed on the right side while the corresponding nerve roots on the left remained intact. The seventh thoracic-nerve root entered fibrous tissue blindly and was sacrificed. Lateral transposition was and should have been accomplished without incident at this level.

In Case 3 the site of the kyphoscoliosis was at the first, second, and third thoracic vertebrae. The bone was chiseled away, and the second and third thoracic-nerve roots were ligated extradurally and sacrificed. This was a risky procedure at this level and theoretically might have produced disability. It is doubtful that this patient's residual neurological deficit can be attributed to the rhizotomy, for the deficit is probably secondary to prolonged compression of the spinal cord.

The patient had progressively improved and made a rather gratifying functional recovery, enabling him to carry on his work and earn his living. It is debatable whether anterior transposition of the cord without rhizotomy would have left him with less neurological disability.

At the time that the author operated upon these three cases just presented, he was rather poorly informed concerning the vascular supply of the spinal cord. Fear of disability in these patients led to further study of this topic with the hope of avoiding increase of neurological deficit after operation. Presumably,

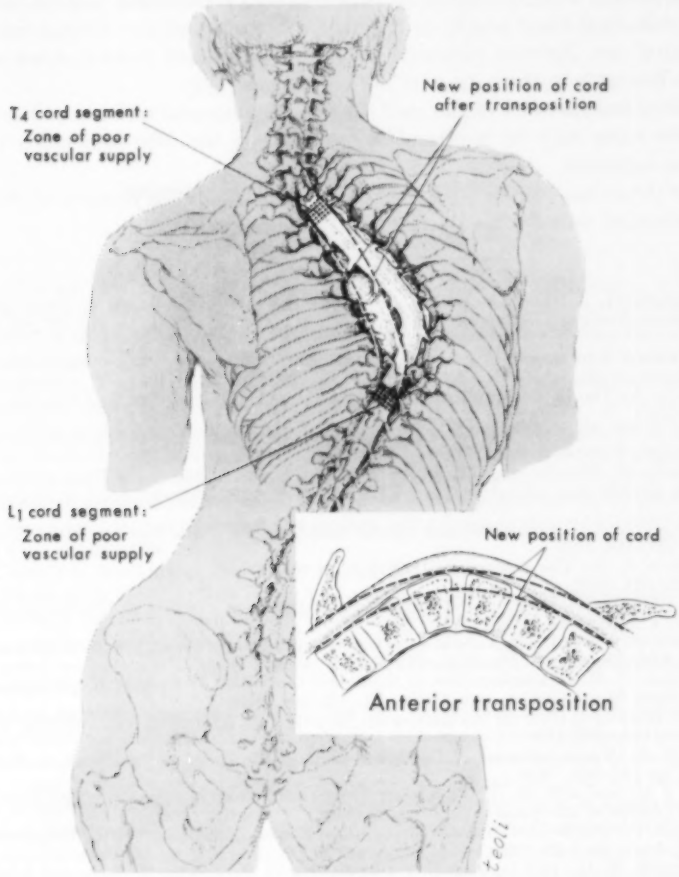

New position of cord after transposition
T_4 cord segment: Zone of poor vascular supply
L_1 cord segment: Zone of poor vascular supply
New position of cord
Anterior transposition
Leali

FIG. 6

Insert: This diagram shows anterior transposition of the spinal cord with simple chiseling away the posterior portion of the vertebral bodies.

Main drawing: This demonstrates the fifth to ninth thoracic vertebral zone where lateral transposition of the cord may be accomplished not only by excision of bone and ribs but also by bilateral rhizotomy, with relatively little concern for vascular insufficiency to the cord.

The fourth thoracic and first lumbar segments of poor collateral blood supply are designated by checkered zones. In these areas it may be safer to resort to anterior transposition of the cord without rhizotomy for fear of compromising the vascular supply.

there is a relatively small amount of collateral blood supply to some portions of the spinal cord but whatever does exist is probably increased gradually as the deformity of the spine progresses with increasing compression of the cord. This was probably true in Cases 2 and 3. The same factor may have been of some importance in Case 1 where the patient sustained an acute spinal-cord injury

superimposed upon the spinal deformity which he had had for a long period of time. Further observations will be necessary to confirm this thesis.

SUMMARY

There is a definite place for transposition of the spinal cord in selected cases of kyphoscoliosis with neurological deficit due to spinal-cord compression. In the three cases presented, there was recovery ranging from a considerable degree to complete restoration of normal function after operation.

The normal vascular supply of the spinal cord is discussed, and the two zones of poor collateral blood supply at the fourth thoracic and first lumbar cord levels are pointed out. *Anterior transposition* of the spinal cord *without rhizotomy* may be more desirable in these areas of critical blood supply.

Lateral transposition of the cord achieved by removal of bone and section of the nerve roots may be without danger between the fifth and ninth thoracic vertebral segments.

The three case reports are discussed with relation to the dangers of rhizotomy with associated vascular insufficiency to the spinal cord.

REFERENCES

1. Adamkiewicz, A.: Die Blutgefässe des Menschlichen Rückenmarkes. I. Die Gefässe der Rückenmarkssubstanz. Sitz.d.k. Akad.d. Wissenschr. in Wien, Math. naturw. Cl., **84:** 469–502, 1881.
2. Alexander, Leo, and Suh, T. H.: Arterial Supply of Lateral Parolivary Area of the Medulla Oblongata in Man. Arch. Neurol. and Psychiat., **38:** 1243–1260, 1937.
3. Bolton, B.: The Blood Supply of the Human Spinal Cord. J. Neurol. and Psychiat., **2:** 137–148, 1939.
4. Dott, N. M.: Skeletal Traction and Anterior Decompression in the Management of Pott's Paraplegia. Edinburgh Med. J., **54:** 620–627, 1947.
5. Evans H. M.: The Development of the Vascular System. *In* Manual of Human Embryology. Vol. 2, pp. 570–623. Edited by Franz Keibel and F. P. Mall. Philadelphia, J. B. Lippincott Co., 1912.
6. Gillilan, L. A.: The Arterial and Venous Blood Supply of the Human Spinal Cord. Anat. Rec., **127:** 466, 1957.
7. Gillilan, L. A.: The Arterial Blood Supply of the Human Spinal Cord. J. Comp. Neurol., **110:** 75–103, 1958.
8. Haymaker, Webb: Bing's Local Diagnosis in Neurological Diseases, p. 478. Ed. 14. St. Louis, The C. V. Mosby Co., 1956.
9. Herren, R. Y., and Alexander, Leo: Sulcal and Intrinsic Blood Vessels of Human Spinal Cord. Arch Neurol. and Psychiat., **41:** 678–687, 1939.
10. Hyndman, O. R.: Transplantation of the Spinal Cord. The Problem of Kyphoscoliosis With Cord Signs. Surg., Gynec., and Obstet., **84:** 460–464, 1947.
11. Kadyi, Heinrich: Über die Blutgefässe des Menschlichen Rückenmarkes. Lemberg, Gubrynowicz und Schmidt, 1889.
12. Love, J. G.: Transplantation of the Spinal Cord for the Relief of Paraplegia. A.M.A. Arch. Surg., **73:** 757–763, 1956.
13. Love, J. G., and Erb, H. R.: Transplantation of the Spinal Cord for Paraplegia Secondary to Pott's Disease of the Spinal Column. Arch. Surg., **59:** 409–421, 1949.
14. Mall, F. P.: On the Development of the Blood-Vessels of the Brain in the Human Embryo. Am. J. Anat., **4:** 1–18, 1905.
15. McKenzie, K. G., and Dewar, F. P.: Scoliosis with Paraplegia. J. Bone and Joint Surg., **31-B:** 162–174, May 1949.
16. Ménard, Victor: Étude Pratique sur le Mal de Pott. Paris, Masson et Cie., 1900.
17. Mettler, F. A.; Cooper, Irving; Liss, Henry; Carpenter, Malcolm; and Noback, Charles: Patterns of Vascular Failure in the Central Nervous System. J. Neuropathol. and Exper. Neurol., **13:** 528–539, 1954.
18. Ross, James: Distribution of the Arteries of the Spinal Cord. Brain, **3:** 80–84, 1880.
19. Sahs, A. L.: Vascular Supply of the Monkey's Spinal Cord. J. Comp. Neurol., **76:** 403–415, 1942.
20. Schneider, R. C., and Crosby, E. C.: Vascular Insufficiency of Brain Stem and Spinal Cord in Spinal Trauma. Neurology, **9:** 643–656, 1959.
21. Seddon, H. J.: Pott's Paraplegia: Prognosis and Treatment. British J. Surg., **22:** 769–799, 1935.
22. Suh, T. H., and Alexander, Leo: Vascular System of the Human Spinal Cord. Arch. Neurol. and Psychiat., **41:** 659–677, 1939.
23. Tureen, L. L.: Circulation of the Spinal Cord and the Effect of Vascular Occlusion. Assn. Res. Nerv. Dis. Proc., **23:** 394–437, 1938.
24. Winkelman, N. W., and Eckel, J. L.: Focal Lesions of the Spinal Cord Due to Vascular Disease. J. Am. Med. Assn., **99:** 1919–1926, 1932.

25. Woodward, J. S., and Freeman, L. W.: Ischemia of the Spinal Cord. An Experimental Study. J. Neurosurg., **13:** 63–72, 1956.
26. Yoss, R. E.: Vascular Supply of the Spinal Cord. The Production of Vascular Syndromes. Univ. Michigan Med. Bull., **16:** 333–345, 1950.
27. Zülch, K. J.: Mangeldurchblutung an der Grenzzone zweir Gefässgebiete als Ursache bisher ungeklärter Rückenmarksschädigungen. Deutsche Zeitschr. f. Nervenh., **172:** 81–101, 1954.

DISCUSSION

Opposition of the Thumb and Its Restoration

(Continued from page 1026)

bone. Dr. Riordan's method of fixation appeals to me, but I have not had a chance to try it out.

Third, improper evaluation of the kinesiology of the extrinsic muscles of the thumb. These muscles must be active, but if they are excessively active they may cause an extension contracture of the metacarpophalangeal joint and ruin the operation. In one such case I had to fuse the joint in a flexed position. Finally, I have had the unpleasant experience of seeing a loss of motive power in the transplant after performing the Steindler tendon shift at the elbow. I probably damaged the motor nerve to the flexor sublimis digitorum controlling the tendon to the fourth finger.

On the whole, the results secured by Dr. Thompson and Dr. Jacobs are excellent, and I congratulate them and their many patients. This is a splendid operation, one of the most brilliant of Dr. Bunnell's operations. The fact that it has been modified in this simple way by Dr. Thompson does not take away from the operation. It has given useful hands to those people who have been suffering from poliomyelitis.

Dr. Emanuel B. Kaplan, New York, N. Y.: This is a valuable report on the experiences in a single institution based on a large number of cases. The results are of importance because they show that the Thompson procedure for restoration of opposition is effective, and that the method can be applied to children with expectation of good functional results. My own limited experience confirms these two findings.

The large number of successful cases proved that careful estimation of the reasons for the loss of opposition, the proper utilization of remaining motors, and the simplicity of the method of repair are three important factors in the restoration of this important function of the thumb.

The review of the kinesiology of opposition is brought out succinctly. It may be necessary, however, to emphasize a few points. In considering the action of opposition, it is necessary to take into account the action of the three components of the thumb. The first component consists of the metacarpocarpal joint and the first metacarpal; the second component is the metacarpophalangeal joint and the proximal phalanx; and the third is the interphalangeal joint and the distal phalanx.

The metacarpocarpal joint is a saddle joint. The only motion possible in this joint is flexion intimately combined with rotation in adduction and in abduction. The metacarpophalangeal joint is capable of flexion and extension, and limited abduction and adduction. The interphalangeal joint has only flexion and extension. The motors acting on the first metacarpal at the metacarpocarpal joint are provided by the abductor brevis, the abductor longus, and extensor brevis, which all act as an abductor. The adduction is produced by the adductor pollicis and the extensor longus pollicis, and also by the first dorsal interosseus. Flexion is produced by the flexor brevis and the opponens. This flexion is transformed into rotation only on account of the configuration of the metacarpocarpal joint (saddle joint).

The motors acting on the metacarpophalangeal joint and the proximal phalanx are the extensor pollicis brevis, which is mostly an abductor of the proximal phalanx and only a very insignificant extensor, and the abductor brevis, which is an abductor of the proximal phalanx and of the first metacarpal and which simultaneously acts as an extensor of the distal phalanx. The extensor pollicis longus may act as an adductor and is an extensor of the proximal phalanx. The adductor pollicis is an adductor of the proximal phalanx and first metacarpal and also an extensor of the

distal phalanx. Flexion of the middle phalanx is produced by the flexor brevis pollicis and additionally by the flexor longus.

The motors acting on the distal phalanx are the extensor longus, as an extensor, and the flexor longus as the only flexor of the distal phalanx. The extension of the distal phalanx is also produced by the abductor brevis and the adductor pollicis when the thumb is in full opposition acting through the dorsal apparatus of the thumb.

Opposition is a complex action in which the three components of the thumb participate somewhat differently for one purpose. The abductor longus acts with the abductor brevis for abduction of the thumb, and the flexor brevis and the opponens flex the first metacarpal, which goes into rotation on account of the saddle configuration of the metacarpocarpal joint. The abductor brevis and the adductor pollicis produce extension of the distal phalanx, acting similarly to the intrinsic muscles of the hand, which produce, simultaneously, flexion of the metacarpophalangeal joint and extension of the distal joint. The flexor longus stabilizes the distal phalanx against the extension action of the abductor brevis and adductor of the thumb.

Any action that is produced in a limb or in a part of a limb is a combined simultaneous response of cortical areas of the brain. The cortex does not contain areas for individual muscles. Any action that occurs in the hand or thumb is due to a wide stimulus, without differentiation and discrimination and without division into individual muscular responses. The restoration of loss of opposition is only a substitution for this marvelous function and can rarely be equaled to the original action. One of the most important problems is restoration of the total functional length of the motors so that there will be sufficiently combined in one unit: flexion of the metacarpophalangeal joint, abduction of the first metacarpal, and extension of the distal phalanx with its stabilization. This is a difficult problem and accounts for the various attempts of insertion of the transplanted motor, for the differences in the choice of the available muscles, and for the uncertain results that are obtained by the more complex methods.

Thompson's procedure is a valuable and non-complex method for restoration of opposition.

DR. THOMPSON (closing): This operation is really quite simple, if you take a good strong muscle and insert it at the right angle. We have had better results with this procedure than with any other. Our best results are with those children on whom the operation is done early, as soon as eighteen months after the attack of poliomyelitis or as soon as we know that the power of opposition will not return. The patients are so happy that they will welcome any operative procedure in view of the good results achieved by this one.

Malignant Disease of the Extremities Treated by Exarticulation

Analysis of Two Hundred and Sixty-four Consecutive Cases with Survival Rates

BY JAMES B. TROUP, M.D., AND WILLIAM H. BICKEL, M.D., ROCHESTER, MINNESOTA

From the Section of Orthopaedic Surgery, Mayo Clinic and Mayo Foundation, Rochester*

Surgical ablation of an extremity demands the ultimate in deliberation on the part of both surgeon and patient. The surgeon must weigh the advantages for the patient against the hazards of the procedure. The patient must realize fully the

TABLE I

Bone Tumors Treated by Hindquarter Amputation
Postoperative Survival of Forty-nine Traced Patients

Histological Type	Grade (Broders)	Patients Total	Traced		Postoperative Survival (*Years*) <1	1	2	3	4	5	10
Chondrosarcoma (32 cases)	1	13	Alive	7			2			2	3*
			Dead	5	1			3		1	
	2	15	Alive	9	3	1	1	1†		1	2
			Dead	5	1	3		1			
	3	4	Alive	2		1				1	
			Dead	2	1			1			
	Total	32	Alive	18	3	2	3	1		4	5
			Dead	12	3	3		5		1	
Osteogenic sarcoma (18 cases)	2	3	Alive	2						2	
			Dead	1	1						
	3	10	Alive	1	1						
			Dead	8	7		1				
	4	5	Alive	2	1						1
			Dead	3	3						
	Total	18	Alive	5	2					2	1
			Dead	12	11		1				
Reticulum-cell sarcoma (1 case)	4	1	Dead	1	1						
Ewing's tumor (1 case)		1	Alive	1	1‡						
Total		52	Alive	24	6	2	3	1		6	6
			Dead	25	15	3	1	5		1	

* One patient had recurrence at amputation site ten and a half years after amputation.
† Right pneumonectomy for metastasis one year previously.
‡ Has pulmonary metastasis.

readjustments that will have to be made in his way of life to meet the emergency. The present report concerns 264 patients who were treated for malignant disease of an extremity by exarticulation at the Mayo Clinic prior to 1959.

Present Series and Operative Mortality

Ninety-five patients have been treated by hindquarter amputation. Nine of these patients had non-malignant disease, including two patients with advanced osteomyelitis, reported by Lewis and Bickel, and one patient with a massive

* The Mayo Foundation, Rochester, Minnesota, is part of the Graduate School of the University of Minnesota.

TABLE II

BONE TUMORS TREATED BY HIP-JOINT DISARTICULATION
POSTOPERATIVE SURVIVAL OF FIFTY-TWO TRACED PATIENTS

Histological Type	Grade (Broders)	Patients Total	Traced	Postoperative Survival (*Years*) <1	1	2	3	4	5	10
Chondrosarcoma (10 cases)	1	5	Alive	4		1		1	2	
			Dead	1						1*
	2	3	Alive	2					2	
			Dead	1		1				
	3	2	Alive	1					1	
			Dead	1	1					
	Total	10	Alive	7		1		1	5	
			Dead	3	1	1				1*
Osteogenic sarcoma (30 cases)	1	1	Dead	1			1			
	2	1	Dead	1			1			
	3	11	Alive	5					2	3
			Dead	6	5					1†
	4	17	Alive	3	2	1				
			Dead	13	5	6	2			
	Total	30	Alive	8	2	1			2	3
			Dead	21	10	6	4			1†
Ewing's tumor (6 cases)		6	Alive	3	1	1				1
			Dead	3	2	1				
Reticulum-cell sarcoma	2	3	Dead	3	1	1				1§
(4 cases)	4	1	Dead	1	1					
Myeloma (1 case)		1	Dead	1				1		
Metastatic hypernephroma (1 case)		1	Dead	1	1					
Parosteal osteogenic sarcoma (1 case)		1	Alive	1	1					
Total		53	Alive	19	4	3		1	7	4
			Dead	33	16	9	4	1		3

* Died of unrelated causes twenty-four years after operation.
† Survived twelve years after disarticulation. What appeared to be metastatic vertebral and rib lesions were seen roentgenographically, but no biopsy was available.
‡ One patient has metastasis to thorax.
§ Died at age seventy-four, after a postoperative survival of ten years.

osteochondroma. Thus, eighty-six of the patients were operated on for malignant disease. The only hospital death was that of a woman, forty-eight years old, who was operated on for malignant disease in 1955 and who died of pulmonary embolism, as proved by necropsy, on the seventh postoperative day.

Eighty-seven disarticulations at the hip joint have been performed without a postoperative death. Eight of these were performed for chronic osteomyelitis or for gangrene of the extremity, leaving seventy-nine that were performed for malignant disease.

Seventy-two forequarter amputations were performed. One of these patients, a seventy-year-old man, sustained a traumatic avulsion of his right upper extremity when his hand was caught in a cement mixer. He died of unrelated causes nine years later. This patient has of course been omitted from this series, since he had non-malignant disease. Also omitted are four patients treated for giant-cell tumor, massive benign chondroblastoma, recurrent fibromyxoma, and actinodermatitis, respectively; the last two proved untraceable, the first one was lost to follow-up after living thirty years postoperatively, and the second was treated too

TABLE III

SOFT-TISSUE TUMORS TREATED BY HINDQUARTER AMPUTATION
POSTOPERATIVE SURVIVAL OF THIRTY-FOUR TRACED PATIENTS

Histological Type	Grade (Broders)	Patients Total	Traced		Postoperative Survival (*Years*) <1	1	2	3	4	5	10
Fibrosarcoma (8 cases)	2	3	Alive	2	1		1*				
			Dead	1						1	
	3	4	Alive	1	1						
			Dead	3	1	2					
	4	1	Alive	1					1		
	Total	8	Alive	4	2		1		1		
			Dead	4	1	2				1	
Liposarcoma (6 cases)	1	1	Alive	1						1†	
	3	4	Alive	2				1		1‡	
			Dead	2	1	1					
	4	1	Dead	1	1						
	Total	6	Alive	3				1		2	
			Dead	3	2	1					
Neurofibrosarcoma (4 cases)	2	2	Alive	1				1			
			Dead	1	1						
	3	2	Alive	1	1						
			Dead	1	1						
	Total	4	Alive	2	1			1			
			Dead	2	2						
Melano-epithelioma (4 cases)	2	3	Alive	2	2§						
			Dead	1	1						
	4	1	Alive	1		1					
	Total	4	Alive	3	2	1					
			Dead	1	1						
Fibromyxosarcoma (3 cases)		3	Alive	3	1				1		1
Rhabdomyosarcoma (2 cases)	4	2	Dead	2	1		1				
Leiomyosarcoma (2 cases)	2	2	Alive	2	2						
Malignant mesenchymoma (2 cases)	3	2	Alive	1			1				
			Dead	1			1				
Synovioma (1 case)	2	1	Alive	1			1				
Squamous-cell epithelioma (1 case)	3	1	Alive	1		1					
Hemangiopericytoma (1 case)		1	Dead	1		1					
Total		34	Alive	20	8	2	3	2	2	2	1
			Dead	14	7	4	2			1	

* Has vertebral metastasis.
† One local recurrent lesion resected five years previously.
‡ Had lobectomy for pulmonary metastasis one year after hindquarter operation—alive without recurrence five years after lobectomy.
§ One patient has recurrence at amputation site.

recently to be included. Thus, sixty-seven patients with forequarter amputations are included in the series.

Of thirty-seven disarticulations at the shoulder joint, two were performed for congenital arteriovenous fistula, one for gas gangrene, one for actinodermatitis, and one for lymphedema. Thirty-two cases are, therefore, discussed in this paper.

In brief, then, of 291 consecutive amputations and disarticulations, 264 were for malignant disease and are the basis for the survival data to be reported. Only one hospital death occurred.

TABLE IV

SOFT-TISSUE TUMORS TREATED BY HIP-JOINT DISARTICULATION
POSTOPERATIVE SURVIVAL OF TWENTY-FIVE TRACED PATIENTS

Histological Type	Grade (Broders)	Patients Total	Traced	Postoperative Survival (*Years*) <1	1	2	3	4	5	10
Fibrosarcoma (9 cases)	3	6	Dead	5	3	1	1			
	4	3	Alive	2					2	
			Dead	1			1			
	Total	9	Alive	2					2	
			Dead	6	3	1	2			
Liposarcoma (5 cases)	1	1	Alive	1	1					
	2	2	Alive	2					2	
	3	2	Alive	1			1			
			Dead	1	1					
	Total	5	Alive	4	1		1		2	
			Dead	1	1					
Neurofibrosarcoma (2 cases)	3	2	Alive	2		1			1	
Fibromyxosarcoma (2 cases)	1	1	Alive	1				1		
	3	1	Alive	1					1	
Rhabdomyosarcoma (2 cases)	3	1	Alive	1	1					
	4	1	Dead	1		1				
Synovioma (2 cases)	3	1	Alive	1					1	
	4	1	Dead	1	1					
Myoblastoma (1 case)		1	Dead	1		1				
Recurrent desmoid (1 case)		1	Alive	1	1					
Squamous-cell epithelioma (1 case)	2	1	Alive	1			1			
Indeterminate small-cell sarcoma (1 case)		1	Dead	1		1				
Total		26	Alive	14	3		1	2	1	7
			Dead	11	5	3	3			

POSTOPERATIVE SURVIVAL

Hindquarter Amputation and Hip-Joint Disarticulation for Bone Tumors (Tables I and II)

As was anticipated, chondrosarcomata constituted a large proportion of the malignant tumors treated by hindquarter amputation and hip-joint disarticulation. Dahlin and Henderson found, in a review of 212 cases of chondrosarcoma, fifty-eight tumors occurring in the ilium and twenty-six in the upper part of the femur. Of the thirty traced patients with chondrosarcoma treated by hindquarter amputation in our series, twelve are now dead from the disease, six of the twelve having died within twenty-four months of operation. Ten of the eighteen surviving patients have lived more than five years postoperatively. The remainder were operated on too recently for such appraisal. Dahlin and Henderson insisted on a ten-year symptom-free period of survival before presuming the patient to be cured. Using this criterion we can consider only four of our thirty traced patients cured.

Six of the ten patients with chondrosarcoma treated by disarticulation at the hip joint lived five or more years after operation; one of these died of unrelated causes twenty-four years after operation. Although this is the only patient that has so far survived for more than ten years, five of the ten have survived more than five years.

TABLE V

BONE TUMORS TREATED BY FOREQUARTER AMPUTATION
POSTOPERATIVE SURVIVAL OF TWENTY-NINE TRACED PATIENTS

Histological Type	Grade (Broders)	Patients Total	Traced	Postoperative Survival (*Years*) <1	1	2	3	4	5	10
Chondrosarcoma (13 cases)	1	4	Alive	4	1				3	
	2	5	Alive	3	3*					
			Dead	2				2		
	3	4	Alive	2	1				1	
			Dead	2		1				1†
	Total	13	Alive	9	5				4	
			Dead	4		1		2		1
Osteogenic sarcoma (12 cases)	2	2	Alive	1					1	
			Dead	1	1					
	3	5‡	Alive	1	1					
			Dead	3		1	2			
	4	5	Alive	1	1§					
			Dead	4	4					
	Total	12	Alive	3	2				1	
			Dead	8	5	1	2			
Reticulum-cell sarcoma (2 cases)	3	1	Dead	1			1			
	4	1	Dead	1	1					
Ewing's tumor (2 cases)		2	Dead	2	1	1				
Myeloma (1 case)		1	Dead	1		1				
Total		30	Alive	12	7				5	
			Dead	17	7	3	3	1	2	1

* One patient has recurrence at amputation site.
† Survived thirty years and died of unrelated causes.
‡ One patient untraced after a postoperative survival of thirty-nine years.
§ Has pulmonary metastasis.

The apparently better five-year survival with hip-joint disarticulation is due to several factors. The patients selected for treatment by disarticulation were those in whom the pathological process had not extended cephalad to the caput femoris by intra-osseous spread, nor had it spread through the soft-tissue planes cephalad to the hip joint. Even if doubt as to such spread existed on gross observation or on biopsy, a hindquarter amputation was performed; hence, many of the more aggressive tumors in the upper part of the femur were included among those subjected to hindquarter amputation.

Another factor adversely affecting the prognosis in hindquarter amputations is the technical difficulty of extirpating, *in toto*, tumors of the ilium. The majority of these were massive, friable, and poorly delineated. Early radical operation has given gratifying results in the treatment of chondrosarcoma of the lower extremity and hemipelvis. Hindquarter amputation done as a last resort, following unsuccessful attempted removal by local resection, offers a far poorer prognosis than it does when done as the primary procedure.

Osteogenic sarcoma constitutes the second main group of bone tumors. The majority of these were found to be of high-grade malignancy and very lethal despite surgical ablation as soon as the diagnosis was made. Of seventeen traced patients treated by hindquarter amputation, eleven were dead of the disease in less than one year. Two patients with Grade 2 lesions have survived more than five years, and one with a Grade 4 lesion has paradoxically lived more than ten years.

Of twenty-nine traced patients with osteogenic sarcoma treated by disarticulation at the hip joint, twenty died of their disease within three years. Six patients

TABLE VI

BONE TUMORS TREATED BY SHOULDER-JOINT DISARTICULATION
POSTOPERATIVE SURVIVAL OF FOURTEEN TRACED PATIENTS

Histological Type	Grade (Broders)	Patients Total	Traced		Postoperative Survival (*Years*) <1	1	2	3	4	5	10
Chondrosarcoma (1 case)	1	1									1*
Osteogenic sarcoma (11 cases)	1	1	Dead	1	1						
	3	9	Alive	1							1†
			Dead	8	3	2	3				
	4	1	Alive	1	1						
	Total	11	Alive	2	1						1†
			Dead	9	4	2	3				
Reticulum-cell sarcoma (1 case)	4	1				1‡					
Ewing's tumor (2 cases)		2	Alive	1					1§		
			Dead	1		1					
Myeloma (1 case)		1	Dead	1			1				
Metastatic hypernephroma (1 case)		1		0							
Total		17	Alive	3	1				1		1†
			Dead	11	4	3	4				

* Untraced after a postoperative survival of thirteen years.
† Survived forty years.
‡ Untraced after surviving one year after operation.
§ Seven-year-old girl had right lower lobectomy for metastasis one and a half years after shoulder-joint disarticulation, and has lived more than two and a half years since lobectomy, without evidence of recurrence.

have survived more than five years. The apparently better five-year survival in disarticulation of the hip may be explained by the fact that the tumor in many of these patients involved only the lower part of the femur and was more definitely ablated by disarticulation.

Among the patients with miscellaneous bone tumors, of particular interest is the patient, seventy-four years old, who survived ten years after disarticulation at the hip joint for reticulum-cell sarcoma of the femur.

Hindquarter Amputation and Hip-Joint Disarticulation for Soft-Tissue Tumors (Tables III and IV)

The most common course followed by the unsuccessfully treated patients with fibrosarcoma and liposarcoma was that of successive recurrences at the amputation site, ultimately with metastasis. Four patients with fibrosarcoma treated by hindquarter amputation are still alive, but were operated on too recently for appraisal. One patient died of the disease after a postoperative survival of five years. For three of those treated by disarticulation, the procedure was regarded as probably palliative at the time of operation; these three patients were dead within one year. Two of the eight traced patients who underwent disarticulation have survived more than five years and are still symptom-free.

Among the other soft-tissue tumors, fibromyxosarcoma appears to have the best prognosis. Four of the five patients in the series were free of recurrence four years after operation.

Forequarter Amputation and Shoulder-Joint Disarticulation for Bone Tumors (Tables V and VI)

Thirteen chondrosarcomata were treated by forequarter amputation, whereas

TABLE VII

SOFT-TISSUE TUMORS TREATED BY FOREQUARTER AMPUTATION
POSTOPERATIVE SURVIVAL OF THIRTY-FIVE TRACED PATIENTS

Histological Type	Grade (Broders)	Patients Total	Traced	Postoperative Survival (*Years*) <1	1	2	3	4	5	10
Fibrosarcoma (9 cases)	1	1	Alive	1					1	
	2	3	Alive	2	1	1				
			Dead	1	1					
	3	3	Alive	1		1				
			Dead	2	1		1			
	4	2	Dead	1	1					
	Total	9	Alive	4	1	2			1	
			Dead	4	3		1			
Squamous-cell epithelioma (7 cases)	2	1	Alive	1					1	
	3	5	Alive	3	1	1		1		
			Dead	2	1				1	
	4	1	Dead	1		1				
	Total	7	Alive	4	1	1		1	1	
			Dead	3	1	1			1	
Rhabdomyosarcoma (5 cases)	3	1	Alive	1		1				
	4	4	Alive	1					1*	
			Dead	2	2					
Fibromyxosarcoma (4 cases)	2	2	Alive	2					1	1
	3	2	Alive	1					1	
			Dead	1		1				
Lymphangiosarcoma (3 cases)		3	Alive	2	1†		1			
			Dead	1		1				
Synovioma (3 cases)	2	2	Alive	1				1		
			Dead	1		1				
	4	1	Dead	1		1				
Liposarcoma (2 cases)	3	1	Alive	1	1					
	4	1	Dead	1	1					
Leiomyosarcoma (1 case)	2	1	Alive	1		1				
Recurrent desmoid (1 case)		1	Alive	1		1				
Melano-epithelioma (1 case)		1	Alive	1		1				
Metastatic adenoma (1 case)	4	1	Dead	1	1					
Total		37	Alive	20	5	6	1	1	1	5	1
			Dead	15	7	3	3	1		1	

* Had right upper lobectomy for metastasis one year after amputation; has had no evidence of recurrence of rhabdomyosarcoma, but is under treatment for adenocarcinoma of large bowel.
† Recurrence at amputation site.

only one was treated by shoulder-joint disarticulation. This is quite understandable when the anatomical distribution of chondrosarcoma is considered. In Dahlin and Henderson's series of 212 chondrosarcomata, nine occurred in the upper part of the humerus and thirteen in the scapula. These patients would be candidates for forequarter amputation. Of the 212 chondrosarcomata, only two occurred in the lower part of the humerus; these patients may be considered candidates for treatment by shoulder-joint disarticulation.

The results of treatment of chondrosarcoma by forequarter amputation are encouraging. One patient died of unrelated causes after surviving thirty years. Four other patients have survived more than five years and are still symptom-free. Two patients survived four years postoperatively and then succumbed to latent metastasis. The one patient treated by disarticulation at the shoulder joint

TABLE VIII

SOFT-TISSUE TUMORS TREATED BY SHOULDER-JOINT DISARTICULATION
POSTOPERATIVE SURVIVAL OF FIFTEEN TRACED PATIENTS

Histological Type	Grade (Broders)	Patients Total	Traced	Postoperative Survival (*Years*) <1	1	2	3	4	5	10
Fibrosarcoma (3 cases)	3	1	Dead	1	1					
	4	2	Dead	2	2					
Squamous-cell epithelioma (5 cases)	2	1	Dead	1	1					
	3	3	Dead	3	1	1			1	
	4	1	Dead	1	1					
Synovioma (2 cases)	3	1	Alive	1	1					
	4	1	Dead	1	1					
Rhabdomyosarcoma (1 case)	3	1	Alive	1						1
Lymphangiosarcoma (1 case)		1	Alive	1		1				
Fibromyxosarcoma (1 case)	2	1	Dead	1					1	
Metastatic adenocarcinoma (1 case)	3	1	Dead	1	1					
Indeterminate small-cell sarcoma (1 case)	4	1	Dead	1		1				
Total		15	Alive	3	1	1				1
			Dead	12	8	2			2	

survived thirteen years and was then lost to follow-up; the tumor was situated in the lower part of the humeral shaft.

Of the eleven traced patients with osteogenic sarcoma treated by forequarter amputation, five were dead from the disease within twelve months and eight were dead within three years. The results with treatment by shoulder-joint disarticulation are comparable, nine patients of eleven being dead from the disease within three years. One patient treated by forequarter amputation survived more than five years, and one was lost to follow-up after a postoperative survival of thirty-nine years. One patient treated by disarticulation survived forty years. There were no factors in the history of these survivors to explain their good fortune.

One patient with reticulum-cell sarcoma of the scapula was symptom-free three years after forequarter amputation.

Forequarter Amputation and Shoulder-Joint Disarticulation for Soft-Tissue Tumors (Tables VII and VIII)

For the most part, forequarter amputation has superseded shoulder-joint disarticulation in the treatment of soft-tissue tumors of the upper extremity. Of the fifteen patients treated by disarticulation of the shoulder joint, the only ten-year survivor so far is a patient with rhabdomyosarcoma. Two patients died of their disease after surviving five years. Eight of the twelve patients who succumbed did so in the first twelve months.

Twenty of the thirty-five traced patients treated by forequarter amputation are still alive, although many of them had been operated on too recently for satisfactory appraisal. Through 1958, seven had survived more than five years after forequarter amputation. Eight of fifteen patients treated by shoulder-joint disarticulation were dead within twelve months of operation, whereas only seven of thirty-five traced patients treated by forequarter amputation succumbed within that period.

TABLE IX

FIVE-YEAR SURVIVAL RATES FOLLOWING MAJOR EXARTICULATIONS FOR MALIGNANT DISEASE OF THE EXTREMITIES

	Patients		Lived Five or More Years after Operation	
	Total	Traced	(*No.*)	(*Per cent*)*
Forequarter amputation	34	32	13	40.6
Hindquarter amputation	41	41	17	41.5
Hip-joint disarticulation	54	53	21	39.6
Shoulder-joint disarticulation	27	26	5	19.2
Total	156	152	56	36.8

* Based on traced patients. Inquiry as of January 1, 1959. Included here are only those patients operated on five or more years prior to the date of inquiry, that is, operated on in 1953 or earlier.

Over-all Survival after Major Exarticulations for Bone Tumors

Osteogenic sarcomata form the largest group with seventy-one cases, and the many elective palliative surgical ablations in this group help to swell the number of patients surviving less than one year. Especially in this group, the aim of ablating the intractably painful, often fungating extremity, is to "allow eventually the least unpleasant demise from metastasis elsewhere."[4] Four of these patients had recognized metastasis at the time of operation. In many of the remaining patients, procedures were done in an attitude of hopeful optimism. We concur with Pack that discouraging prognostic factors are surgical intervention including biopsy without immediate definitive treatment, extensive local progression of the tumor —especially if this had become extra-osseous—and tumors that are technically of borderline operability. Duration of symptoms for a period greater than three months adversely affected the prognosis. Through 1958, eleven of the sixty-eight traced patients had survived more than five years.

The fifty-six patients with chondrosarcoma have had far more gratifying results. Through 1958, twenty-one of fifty-three traced patients had survived more than five years. According to Dahlin and Henderson's criterion, the thirteen patients alive and well after five years must still be regarded as representing only potential absolute cures.

Of the seven traced patients with reticulum-cell sarcoma, only one survived ten years. The latter patient was treated before the radiosensitivity of these tumors was fully appreciated, and hence did not have roentgen therapy.

Over-all Survival after Major Exarticulations for Soft-Tissue Tumors

Of twenty-seven traced patients with fibrosarcoma, only four have survived more than five years. One of these died in the sixth postoperative year. Seven other living patients were operated on too recently for appraisal. These figures emphasize the poor prognosis of fibrosarcoma. The malignancy of this disease often appears to be underestimated, judging by the many attempts made at local resection before amputation is finally resorted to.

Two of the fourteen patients treated for squamous-cell epithelioma died of their disease after having survived five years. It is difficult to determine when a patient can be regarded as cured of this relentlessly recurring tumor. Certainly forequarter amputation, in which the regional lymph nodes are ablated, appears to offer a better outlook than does shoulder-joint disarticulation.

Both patients with Grade 4 liposarcoma succumbed within twelve months. The prognosis in the lower grades of liposarcoma appears to be greatly improved if

the exarticulation is performed at the time of biopsy, without previous surgical interference with the tumor, although the smallness of the group (thirteen cases) makes such an observation inconclusive.

In our series the duration of symptoms in patients with synovioma was longer than in patients with most other soft-tissue tumors, because of underdiagnosis on clinical grounds, a benign synovial disease being suspected while the swelling was observed.

Of all the soft-tissue tumors in this series, fibromyxosarcoma was associated with the best survival figures. Six of the ten patients survived more than five years after operation. Through 1958, another two patients had been asymptomatic for four years. Three of the patients surviving five years had had attempts at local resection before the exarticulation.

Of the 109 traced patients with soft-tissue tumors, twenty had survived more than five years, through 1958.

Five-Year Survival Rates

The five-year survival rates for the various operative procedures are given in Table IX.

COMMENT AND SUMMARY

This analysis of major exarticulations performed for malignant disease of the extremities encountered at the Mayo Clinic indicates that the survival rates were adversely affected by the patients who received surgical treatment as a palliative measure. Conversely, some patients regarded as having a very dismal prognosis have had a surprisingly long postoperative survival. It can only be conjectured at the present time that the protracted survival of patients in whom cancer cells were known to have been left in the body at the time of operation may be attributable in part to the patient's own resistance to cancerous invasion.

Gordon-Taylor has suggested that a tumor may have the metabolic balance turned against it by some metabolic alteration of the parent organism and may cease growing for a variable time and even become smaller, only to assume its proliferative activity again at a later period. This seems a logical hypothesis.

Major exarticulation is now acceptable treatment for many types of malignant disease of the extremities. Except for palliative operations, forequarter amputation is now preferred by many to shoulder-joint disarticulation for the treatment of malignant disease of the upper part of the arm. In many cases, these procedures offer the patient the only existing chance of survival.

The five-year survival rates were respectively 40.6 per cent for forequarter amputation, 41.5 per cent for hindquarter amputation, 39.6 per cent for hip-joint disarticulation, and 19.2 per cent for shoulder-joint disarticulation. The survival rate for these operations as a combined group was 36.8 per cent.

REFERENCES

1. Dahlin, D. C., and Henderson, E. D.: Chondrosarcoma, A Surgical and Pathological Problem. Review of 212 Cases. J. Bone and Joint Surg., **38-A:** 1025–1038, Oct. 1956.
2. Gordon-Taylor, Gordon: The Incomputable Factor in Cancer Prognosis. British Med. J., **1:** 455–462, 1959.
3. Lewis, R. C., Jr., and Bickel, W. H.: Hemipelvectomy for Malignant Disease. J. Am. Med. Assn., **165:** 8–12, 1957.
4. Osmond-Clarke, H.: Amputations; Editorial and Annotations. J. Bone and Joint Surg., **39-B:** 218–219, May 1957.
5. Pack, G. T.: Major Exarticulations for Malignant Neoplasms of the Extremities: Interscapulothoracic Amputation, Hip-Joint Disarticulation, and Interilio-Abdominal Amputation. A Report of End Results in 228 Cases. J. Bone and Joint Surg., **38-A:** 249–262, Apr. 1956.

Volar Transnavicular Perilunar Dislocation of the Carpus

BY ALEXANDER P. AITKEN, M.D., AND EDWARD A. NALEBUFF, M.D.*
BOSTON, MASSACHUSETTS

From the Orthopaedic Service, Boston City Hospital, Boston

Perilunar dislocations of the carpal bones are unusual injuries. The literature contains many excellent reviews [2,3,5] in which the usual dorsal dislocations are discussed. Recently, we had the opportunity to treat a rare volar perilunar dislocation of the carpal bones with fracture of the navicular. To our knowledge, very few similar cases have been reported. It is believed that this lesion will be of interest to other orthopaedic surgeons because of its unusual nature and that a comparison of this lesion with its more common dorsally displaced counterpart will shed light on its mechanism and nature.

Russell reviewed fifty-nine cases of carpal dislocation in the personnel of the Royal Air Force during World War II. He included twenty-seven cases of perilunar dislocation with transnavicular fracture, which were all of the dorsal type. MacAusland, in a series of twenty-four carpal dislocations, described nine instances of perilunar dislocation, one of which was described as showing volar perilunar dislocation of the carpal bones without fracture of the navicular. Speed, in his extensive monograph on carpal injuries, described one volar dislocation of the carpal bones associated with fracture of the navicular. A review of the hospital admissions to the Fracture Service of the Boston City Hospital for the past twenty years revealed no instance of volar perilunar dislocation of the carpal bones with fractures of the navicular, further indicating the rarity of this lesion.

A male student barber, twenty-one years old, fell off a ladder from a second-story level, and landed on the dorsum of the flexed hand. At the Shortell Unit of the Boston City Hospital, examination revealed a moderately swollen hand and wrist. There was no evidence of either nerve or vascular injury. The patient was unable to move his wrist and could flex his fingers only slightly.

Roentgenograms revealed a volar perilunar dislocation of the carpal bones with fracture of the navicular (Figs. 1-A and 1-B). The larger distal fragment of the navicular was displaced anteriorly with the other carpal bones, whereas the small proximal fragment remained with the lunate.

The patient was given 100 milligrams of demerol, and a closed reduction was carried out. Traction was applied to the flexed hand while an assistant gave countertraction to the forearm. The hand was then extended, and a reduction was easily obtained. At this time, the muscle spasm that had been present subsided, and the surgeon (E.A.N.) was able to displace and reduce the dislocation at will. It was noted that the dislocation was unstable in flexion but could be easily maintained in moderate extension. A double sugar-tong plaster cast was applied, and the thumb was immobilized in a position of function. Postreduction roentgenograms revealed an adequate reduction (Figs. 1-C and 1-D).

The patient was admitted to the hospital, and roentgenograms made seventy-two hours later showed maintenance of the position. The patient was discharged from the hospital and was followed in the Out-Patient Department. After two weeks, the wrist appeared clinically normal and was not painful. A new plaster-of-Paris gauntlet was applied. At ten weeks the plaster gauntlet was removed. Examination revealed a normal-appearing wrist with surprisingly good function. The extremes of flexion and extension of the wrist were lost, but the patient exhibited full supination and pronation. Roentgenographic examination showed that both fragments of the navicular were viable but not united and that there was minimum displacement. The patient did not wish to continue the immobilization and chose to return to barber school. At the follow-up examination

* National Foundation Fellow.

FIG. 1-A

FIG. 1-B

Fig. 1-A: Volar perilunar dislocation of the carpal bones after a fall on the dorsum of the flexed hand. Note the normal relationship of the lunate and the radius.

Fig. 1-B: Anteroposterior roentgenogram.

FIG. 1-C

FIG. 1-D

Anteroposterior and lateral roentgenograms, showing satisfactory reduction of the fracture-dislocation. The wrist was immobilized in slight extension.

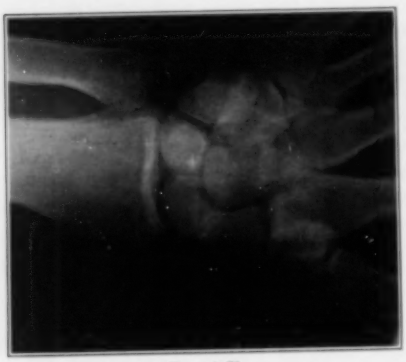


FIG. 1-E

FIG. 1-F

Fig. 1-E: Anteroposterior roentgenogram of the wrist fourteen months after the injury, showing increased density of the lunate, indicating aseptic necrosis of the lunate with non-union of the navicular.

Fig. 1-F: Oblique roentgenogram of the wrist twenty months after injury, showing a decrease in the density of the lunate with persistence of non-union of the navicular.

fourteen months after injury, the patient continued to be asymptomatic, but roentgenograms showed increased density of the lunate, indicating aseptic necrosis (Fig. 1-E). The patient continued to work full time as a barber and when last examined, two and one-half years after the

injury, he had a normally functioning wrist, and there was roentgenographic evidence of revascularization of the lunate (Fig. 1-F). The navicular fracture continued to show non-union.

MECHANISM OF INJURIES

Extension Injuries

In falls on the extended hand, either an anterior dislocation of the lunate or a retrolunar dislocation of the other carpal bones may be produced, depending

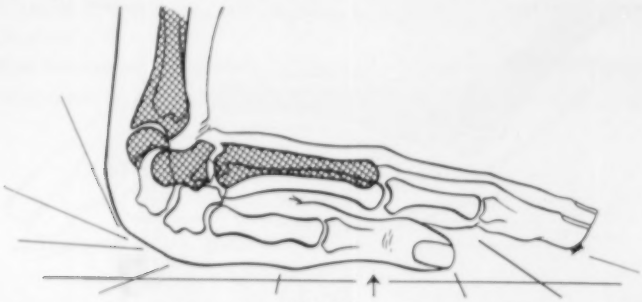


FIG. 2-A

Schematic drawing of a roentgenogram, showing the position of the carpal bones with the wrist in extreme extension. The capitate has rotated dorsally on the lunate.

FIG. 2-B

Roentgenogram of volar dislocation of the lunate (first-degree) after a fall on the palmar surface of the hand, forcing the wrist into extreme extension. Note the abnormal relationship between the radius and the lunate.

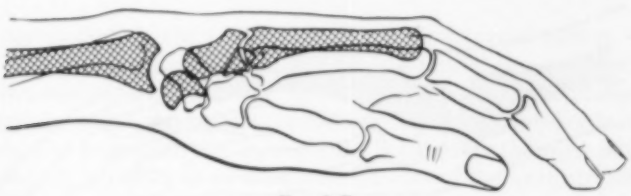


FIG. 2-C

Schematic drawing of a roentgenogram, showing volar dislocation of the lunate.

on the degree of extension and the direction of force. If, in the fall, the hand is close to the body, the force is directed against the fingers and the metacarpal heads, causing extreme hyperextension of the hand, particularly in the carpal region. The capitate, rotating dorsally on the lunate, forces it out of the wrist as a seed is popped from a pod (Figs. 2-A through 2-C). If the hand is away from the body, the force is directed against the palm, resulting in less extension of the carpal bones. The direct force thus applied drives the other carpal bones

posteriorly behind the lunate, causing a dorsal perilunar dislocation (Figs. 3-A through 3-C).

Flexion Injuries

In falls on the dorsum of the hand when the hand is close to the body, extreme flexion occurs; the capitate, rotating on the lunate, drives the lunate dorsally

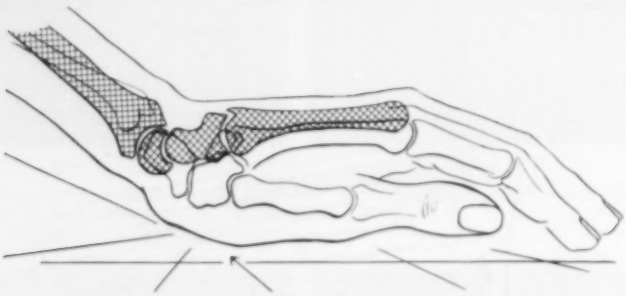


FIG. 3-A

Schematic drawing, showing the position of the carpal bones with the wrist in moderate extension. In this position the capitate has rotated slightly on the lunate and is susceptible to dorsal perilunar dislocation.

FIG. 3-B

Roentgenogram of dorsal perilunar dislocation of the carpal bones. Note that only the lunate has maintained its relationship with the radius. The capitate and the remainder of the carpal bones have been displaced posteriorly. This injury followed a fall on the outstretched hand with the wrist in moderate extension.

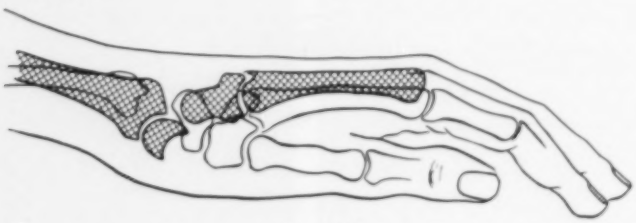


FIG. 3-C

Schematic drawing of a roentgenogram, showing perilunar dislocation of the carpal bones.

out of the wrist joint, producing the rare dorsal dislocation of the lunate (Figs. 4-A and 4-B). Such a case was reported by Hermann. If the hand is away from the body, less flexion occurs, and the direct force drives the other carpal bones anterior to the lunate, producing a volar perilunar dislocation of the carpal bones (Figs. 1-A, 1-B, 5-A, and 5-B). The instinctive attempt of the falling person to land on the palm of the outstretched hand renders the extension injuries far more

common. Fracture of the navicular usually occurs in both types of perilunar dislocation.

MANAGEMENT

Accurate diagnosis of the injury is essential to the proper treatment of all carpal dislocations. Retrolunar dislocation of the carpus is commonly misdiagnosed as volar dislocation of the lunate, and, occasionally, a normal lunate is excised [6]. Careful attention to the relation of the radius and the lunate should obviate this error.

The ideal treatment is closed reduction and plaster immobilization in a stable position. Reduction is accomplished by traction on the hand, with an assistant

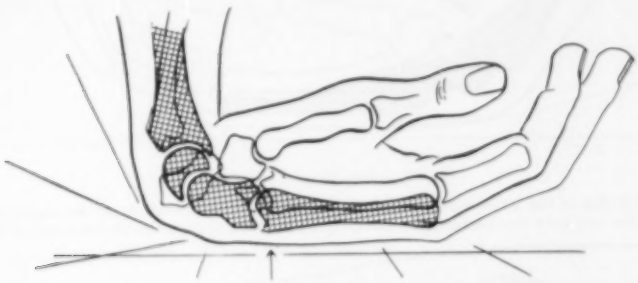


FIG. 4-A

Schematic drawing of the wrist in extreme flexion. Note that the capitate has rotated anteriorly. In this position, the lunate is forced out posteriorly by a force applied to the dorsum of the hand.

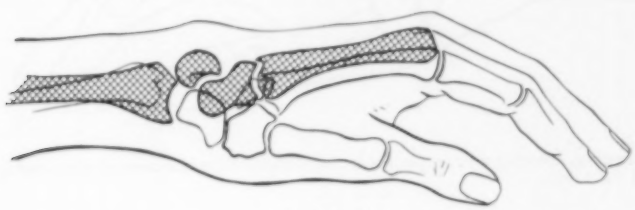


FIG. 4-B

Schematic drawing of a roentgenogram, showing a dorsal dislocation of the lunate. This is a rare injury. A single instance is shown in Speed's monograph on carpal injuries.

giving countertraction on the forearm. In the more common variety of dorsal perilunar dislocation, the hand and carpus are maintained in a position of volar flexion. In the case reported, a closed reduction was easily accomplished by the reverse procedure, and it was noted that the dislocation was stable only in moderate extension. The immediate aim in treatment is to reduce the perilunar dislocation. However, the presence of an associated fracture of the navicular affects the further management of the case and may have a profound effect on the ultimate prognosis.

The period of immobilization of dislocations not associated with fracture of the navicular is usually from four to six weeks. However, the average period of immobilization when there is a fracture of the navicular is from three to five months.

Wagner believed that open reduction of perilunar dislocation associated with fracture of the navicular, with or without bone-grafting or removal of the proximal fragment, uniformly leads to poor results. He, therefore, recommended primary arthrodesis of the wrist in instances in which anatomical reduction of the navicu-

lar is not obtained, in the belief that this management would shorten the period of disability. It has been our experience that open reduction is usually not necessary, but we would not hesitate to perform open reduction with internal fixation of the navicular. We would not agree that primary wrist fusion is indicated.

PROGNOSIS

The prognosis in all perilunar dislocations is guarded, particularly when associated with fracture of the navicular. The vascular damage to the navicular in

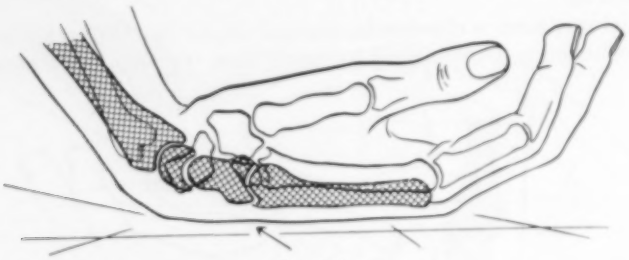


FIG. 5-A

Schematic drawing of the wrist in moderate flexion, showing the position of the carpal bones. In this position, the capitate can be forced anteriorly by a force applied to the dorsum of the hand.

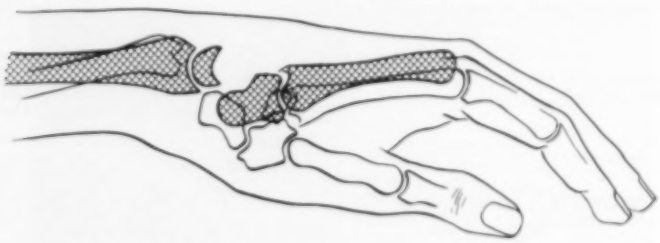


FIG. 5-B

Schematic drawing, showing a volar perilunar dislocation. Note the normal relationship between the radius and the lunate.

these injuries is far greater than that which occurs in simple fractures of the navicular. Even with anatomical reduction of the fragments, aseptic necrosis of the proximal fragment may occur in 50 per cent of the fractures, and, with displacement of the fragments, the necrosis rate may be much higher.

No one has had extensive experience with volar perilunar dislocation associated with fracture of the navicular, but it seems likely that the management and prognosis in this injury would be similar to that of the dorsal dislocation. In the one case reported by Speed, no mention of the management or of the result is given. In MacAusland's patient with volar perilunar dislocation, without a fractured navicular, there was a late dislocation of the lunate; the lunate was later excised with a poor result. In the patient we have presented, some evidence of aseptic necrosis of the lunate developed but is resolving. The persistent non-union of the navicular may yet lead to difficulty.

SUMMARY

A case history of an extremely rare volar perilunar dislocation of the carpus with fracture of the navicular has been presented. The mechanism of injury in this patient was a force directed to the dorsum of the partially flexed hand. This fracture-dislocation presents the reverse picture of the more common dorsal perilunar dislocation.

Our explanation of the mechanism of the production of lunar and perilunar dislocation is presented.

REFERENCES

1. Hermann, O. J.: Personal communication.
2. MacAusland, W. R.: Perilunar Dislocation of the Carpal Bones and Dislocation of the Lunate Bone. Surg., Gynec., and Obstet., **79:** 256–266, 1944.
3. Russell, T. B.: Inter-carpal Dislocations and Fracture-Dislocations. A Review of Fifty-nine Cases. J. Bone and Joint Surg., **31-B:** 524–531, Nov. 1949.
4. Speed, Kellogg: Traumatic Injuries of the Carpus. Including Colles' Fracture. New York, D. Appleton and Co., 1925.
5. Wagner, C. J.: Perilunar Dislocations. J. Bone and Joint Surg., **38-A:** 1198–1207, 1230, Dec. 1956.
6. Watson-Jones, Reginald: Fractures and Joint Injuries. Ed. 4. Vol. II, p. 626. Baltimore, The Williams and Wilkins Co., 1955.

Duplication of Hypothenar Muscles Simulating Soft-Tissue Tumor of the Hand

Report of a Case

BY PAUL R. LIPSCOMB, M.D., ROCHESTER, MINNESOTA

*From the Section of Orthopaedic Surgery, Mayo Clinic and Mayo Foundation *, Rochester*

Anomalous muscles in the hand may simulate soft-tissue tumors. It is the purpose of this communication to record a rare muscle anomaly in the hypothenar region which was explored on the assumption that it was a tumor.

REPORT OF A CASE

In 1957 a boy, seventeen years of age, came to the Mayo Clinic with the chief complaint of a growth in the left hand. He stated that since birth this hand had been slightly larger than the other

FIG. 1

Anteroposterior roentgenogram of the left hand. Note soft-tissue enlargement along ulnar side.

* The Mayo Foundation, Rochester, Minnesota, is a part of the Graduate School of the University of Minnesota.

FIG. 2

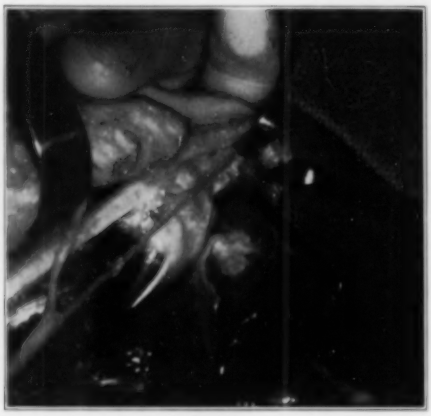


FIG. 3

Fig. 2: Appearance of anomalous muscle in hypothenar eminence. Skin and middle head of muscle are being retracted radially and the ulnar nerve, just below the pisiform bone, is being retracted medially with nerve tape. Tape overlies the large palmaris brevis muscle that has been detached laterally but is still attached medially. Just distal to the palmaris brevis muscle is the most proximal head of the triangular anomalous muscle mass which has been detached from its origin. Note that sensory branches of the ulnar nerve pass posterior or deep to the retracted middle head of muscle, which has not yet been detached proximally, but pass superficial to the large distal head.

Fig. 3: The conjoined tendon of the three heads of the mobilized triangular muscle passes to its insertion on the medial side of the base of the proximal phalanx of the little finger. This tendon is seen just posterior to the proper volar digital nerve and close to the tip of the most distal retractor. The three muscle bellies now lie along the ulnar border of hand, and are being pulled in a longitudinal direction.

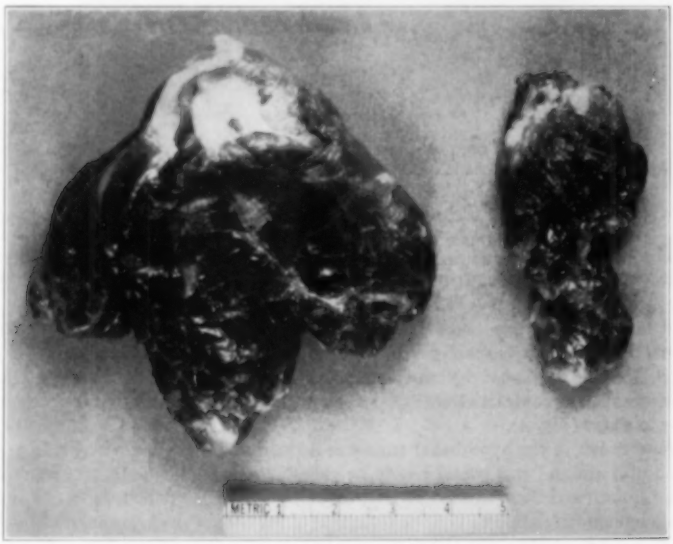


FIG. 4

Excised triangular muscle with three heads of origin (below) and conjoined tendon of insertion on reader's left, and a portion of enlarged palmaris brevis muscle on right.

but that about one year previously it had begun to enlarge and the little finger had started locking, usually in flexion but occasionally in extension. Pain had not been a feature. The patient was able to demonstrate the locking; it was typical of that seen in trigger-finger. The hypothenar eminence was markedly enlarged by a soft globular mass. The roentgenogram (Fig. 1) showed a soft-tissue enlargement, which did not have the characteristics of a lipoma. It was thought that the lesion was some soft-tissue tumor such as a lymphangioma, neuroma, or hemangioma. Surgical exploration was advised.

On July 12, 1957, the mass was explored through a curved incision which extended along the ulnar border of the hand and then transversely across the wrist just proximal to the pisiform bone. Upon reflection of the skin and subcutaneous tissues of the palm, a large palmaris brevis muscle, approximately six times normal size, was encountered. Reflection of this muscle ulnarward, instead of exposing the ulnar artery and nerve lying just distal and radial to the pisiform as would be anticipated in the normal hand, disclosed a large muscle consisting of three heads which converged to insert by a common tendon into the base of the proximal phalanx of the little finger (Figs. 2 and 3). The most proximal of these heads arose from the pisiform bone and hook of the hamate. The next head arose from the palmar fascia at the insertion of the palmaris longus tendon. The third and most distal head of the anomalous muscle arose from the distal end of the transverse carpal ligament and deep palmar fascia. This distal muscle head was dorsal to the common and proper volar digital nerves which arise from the ulnar nerve, whereas the two proximal heads of the muscle were

FIG. 5

Hypothenar eminence after excision of anomalous muscle mass and a portion of enlarged palmaris brevis muscle; part still remaining can be seen on reader's right. Note small muscle belly with long tendon just to left of remaining palmaris brevis. This appeared to be a small abductor digiti quinti. Flexor and opponens digiti quinti muscles can be seen beneath branches of the ulnar nerve.

superficial to the ulnar nerve and its branches. An anomalous mid-palmar artery coursed in a longitudinal direction over the center of the mass. Small branches from the ulnar nerve innervated the muscle. The three bellies of the muscle with its common tendon of insertion were excised. Even after excision and in its contracted state the muscle measured six by five by two centimeters and was triangular in shape (Fig. 4).

There were left in the hypothenar eminence a small muscle that originated from the medial side of the pisiform and was considered to be the abductor digiti quinti, an apparently normal flexor digiti quinti, and the opponens digiti quinti (Fig. 5). The abductor digiti quinti muscle had a long, thin tendon which inserted on the ulnar side of the base of the proximal phalanx of the little finger. Because of the history of locking, the proximal pulley of the fibrous flexor sheath of the little finger was partially excised. The major portion of the enlarged palmaris brevis muscle was also excised, and the remainder was attached laterally to the base of the skin flap. The main motor branch of the ulnar nerve appeared normal as it dipped into the adductor muscle of the thumb. Excess skin was excised, the wound was closed with interrupted wire sutures, and a compression dressing was applied. The patient's convalescence was uneventful. He has not been re-examined but in a recent letter, two and one-half years after operation, he stated that his hand is normal with a complete and free range of motion of all digits.

COMMENT

The photographs made during the operation were reviewed by Dr. Emanuel

B. Kaplan. He suggested that the anomalous muscle mass represented a duplication of the hypothenar muscles and referred me to the works of Le Double, Bryce, Jones, and Humphry. These authors described anomalies of the palmaris brevis and hypothenar muscles, including bilateral duplication of the abductor digiti quinti and an abductor digiti quinti with two heads. No anomaly comparable to the one found in the case reported here was described.

Whether the large, anomalous muscle, which arose by three heads and was entirely excised, represented duplication of the three muscles of the hypothenar eminence or was an anomalous single muscle cannot be established but after its removal three hypothenar muscles were left. The smaller of these appeared to be an abductor digiti quinti muscle, and there is little doubt that the anomalous superficial muscle, whose fibers ran transversely, was a very large palmaris brevis. Le Double and Bryce stated that the dimensions of the palmaris brevis vary considerably.

SUMMARY

An unusual muscle anomaly is reported which simulated a soft-tissue neoplasm in the hand. It was considered to be a duplication of the hypothenar muscles. No identical case could be found in the literature. The function and appearance of the hand are reported to be excellent almost three years after excision of the anomalous three-headed muscle and the major portion of a very large palmaris brevis muscle. Section of the proximal pulley of the distal fibrous flexor tendon sheath of the little finger, because of a trigger finger, was also performed.

REFERENCES

1. Bryce, T. H.: Myology. *In* Quain's Elements of Anatomy. Vol. IV, Part II, Ed. 11. New York, Longmans, Green and Co., 1923.
2. Humphry, G. M.: Observations in Myology. London, Macmillan and Co., Ltd., 1872.
3. Jones, F. W.: The Principles of Anatomy as Seen in the Hand. London, J. and A. Churchill, Ltd., 1920.
4. Kaplan, E. B.: Personal communication.
5. Le Double, A. F.: Traité des Variations du Système Musculaire de l'Homme, et de leur Signification au Point de Vue de l'Anthropologie Zoologique. Vol. II. Paris, Schleicher Frères, 1897.

Extra-Articular Hip Arthrodesis

Salvage Procedure for Persistent Pain Following Replacement Arthroplasty: A Case Report

BY S. S. COLEMAN, M.D., AND W. S. HUNTER, M.D., SALT LAKE CITY, UTAH

From the Orthopaedic Department, Salt Lake County General Hospital, Salt Lake City

Extra-articular arthrodesis of the hip about a retained intramedullary stem prosthesis may occasionally be indicated when there is persistent disabling pain and marked restriction of motion. This procedure has certain advantages because femoral length and stability are preserved, and the procedure is simpler than it would be if the prosthesis was removed. A possible disadvantage is the retention of a large foreign body within the hip, the fate of which is as yet not known. The patient in this report had a series of unsuccessful operations about the left hip, culminating in an arthrodesis that was performed as a salvage procedure, with an Austin Moore prosthesis left *in situ*. The case is reported because it illustrates a possible solution to a difficult problem. No similar report was found in the review of the available literature for the past ten years.

CASE REPORT

A white woman, thirty-nine years old, was first seen by us in January 1958. The patient recalled that she had been treated at the age of nine for a painful disability of the left hip. Throughout adolescence she had had mild discomfort in the hip, and during her adult life the pain had gradually increased in severity, probably aggravated by six full-term pregnancies. Roentgenograms of the pelvis, made in 1950 for obstetrical reasons, showed degenerative changes in the left hip (Fig. 1). Increasing pain and progressive loss of motion justified a cup arthroplasty in September 1954 (Fig. 2). The result of this operation was poor; the hip remained painful and stiff. An adductor tenotomy

FIG. 1

FIG. 2

Fig. 1: Roentgenogram made in 1950, when the patient was thirty years old; the degenerative changes in the left hip joint are shown.

Fig. 2: Roentgenogram made after Vitallium-cup arthroplasty in 1954; the patient was thirty-four years old.

FIG. 3

FIG. 4

Fig. 3: Postoperative roentgenogram made in 1955, showing replacement of the Vitallium cup by an Austin Moore prosthesis.

Fig. 4: Roentgenogram made in 1958, fifteen months after the attempted ischiofemoral arthrodesis. Note the pseudarthrosis at the ischial end of the graft.

FIG. 5

Roentgenogram made in April 1960, sixteen months after extra-articular arthrodesis. The iliofemoral graft is solidly incorporated in the fusion mass, and the ischiofemoral pseudarthrosis has healed. Note the absence of reaction about the prosthesis.

and obturator neurectomy were performed in January 1955, with little improvement in pain or motion. A second tenotomy was performed in March 1955 to correct an adduction contracture.

In November 1955, because of continued pain, an Austin Moore prosthesis was inserted (Fig. 3) because the patient refused arthrodesis at this time. This procedure failed to relieve her symptoms, and by August 1957 she had only a few degrees of painful motion. An ischiofemoral arthrodesis was attempted in August 1957 with full-thickness iliac bone used as the graft. By November 1958, a pseudarthrosis was apparent in the ischial portion of the graft, and the patient continued to have pain and disability (Fig. 4).

Her symptoms were sufficiently great to justify a second attempt at fusion; therefore, in December 1958 an anterior iliofemoral fusion was performed. A massive full-thickness iliac graft was laid over the ilium and the remaining neck and trochanter and was held in place with four screws. The patient was immobilized in a one and a half hip spica cast until June 1959, when roent-

genograms showed not only that the iliofemoral arthrodesis was sound, but also that the ischiofemoral pseudarthrosis had healed. She then resumed full unrestricted weight-bearing at that time.

When last examined in April 1960, the hip was entirely painless, and the patient was doing all her own housework for the first time in six years; she was also leading an active social life and was happy and satisfied with the result. Roentgenograms at that time showed a solid arthrodesis with normal bone and no evidence of reaction about the retained prosthesis (Fig. 5). The patient's convalescence from her arthroplasties had been hampered by her inability to cooperate in physical therapy, which may have contributed to the failure of the operative procedure. On the other hand, it is also possible that the operative technique employed in these operations was less than ideal and was responsible to some extent for her pain and difficulty in the performance of her exercises during convalescence.

CONCLUSIONS

Fusion of the hip after the removal of a prosthesis has several disadvantages, chief among which is loss of femoral length. Arthrodesis with retention of the prosthesis preserves femoral length. Also, the operative procedure is simpler and carries less morbidity than if the prosthesis is removed. A possible drawback is the retention of a large metallic foreign body. In selected cases, it appears that the advantages of the procedure outweigh its disadvantages.

This method of salvage appears to be best suited to the patient who has markedly restricted hip motion, who is not too old or infirm to tolerate prolonged plaster immobilization, and who needs a painless stable hip.

NOTE: We are indebted to Dr. E. J. Horsley of Denver, Colorado, who performed the ischiofemoral fusion and who originally suggested arthrodesis in this patient.

Malignant Bone Tumors in Siblings

Ewing's Tumor and an Unusual Tumor Perhaps a Variant of Ewing's Tumor

A Case Report

BY ROBERT W. HUNTINGTON, JR., M.D., DONALD J. SHEFFEL, M.D., MORTIMER IGER, M.D., AND CHARLES HENKELMANN, M.D., BAKERSFIELD, CALIFORNIA

From the Orthopaedic Service, the Tumor Board, the Radiology Service, and the Department of Pathology, Kern County General Hospital, Bakersfield, and the Department of Pathology, University of Southern California School of Medicine, Los Angeles

We wish to report the histories of two sisters who both had malignant disease. One sister (C. R. M.) died at nineteen years of age, approximately two and one-half years after the appearance of a tumor that was classified as Ewing's tumor [3, 27]. The other sister (M. J. E.) had extensive metastatic disease and at the time of writing was twenty-five years old; six and one-half years previously she had had a high amputation of the humerus because of an unusual tumor of the radius that had such striking epithelial characteristics that the possibility that it was either metastatic carcinoma or an adamantinomatoid tumor was seriously considered [2, 7, 8, 20, 27]. However, when the patient had no evidence of another primary tumor after five years, it seemed most unlikely that the radial lesion was a metastasis. During the sixth year after the amputation, a tumor appeared in the lung and pleura that was considered to be metastatic from the radius, even though the histological pattern of the lesion in the lung lacked the epithelial features of the lesion in the radius and resembled the pattern of C. R. M.'s tumor. Without a more plausible hypothesis, we have concluded that M. J. E.'s pleural and radial lesions are related and that M. J. E.'s primary tumor will have to be classed tentatively as an unusual or, perhaps, as a unique variant of Ewing's tumor [21].

At the least, the occurrence of these neoplasms in two sisters represents an extraordinary coincidence. The principal reason for reporting these two cases is to record the unusual history, histology, and diagnostic problem of M. J. E.'s tumor and to add this family to the available records on familial incidence of bone tumors [12, 21, 23]. Of eighty Mayo Clinic patients with Ewing's tumor, McCormack and associates found one with a history of bone sarcoma in a sibling. Osteosarcoma in two or more children of a family was reported [12]. We have not seen such a family, although one of our patients with osteosarcoma [13], whose mother, at the time of writing, has carcinoma of the cervix and whose father died of a Grade IV astrocytoma [14], may appropriately arouse a little curiosity as to genetic or environmental carcinogens.

M. J. E., born in 1934, was the third child and C. R. M., born in 1939, was the fourth child in a Caucasian family of eight children. At the time of writing, none of the other siblings (five boys and one girl) had shown evidence of bone tumor: the four younger ones had skeletal roentgenographic surveys in 1957. At the time of writing, the father and mother, the paternal grandparents, the maternal grandmother, and several paternal aunts and uncles were living and well. The paternal grandmother, apparently the most reliable informant, knew of no one in the family other than M. J. E. and C. R. M. who had suffered from "bone cancer or any other kind of cancer".

Because M. J. E. has two children, and C. R. M. is survived by one child, it will be of some interest to follow the next generation. Shortly after C. R. M.'s

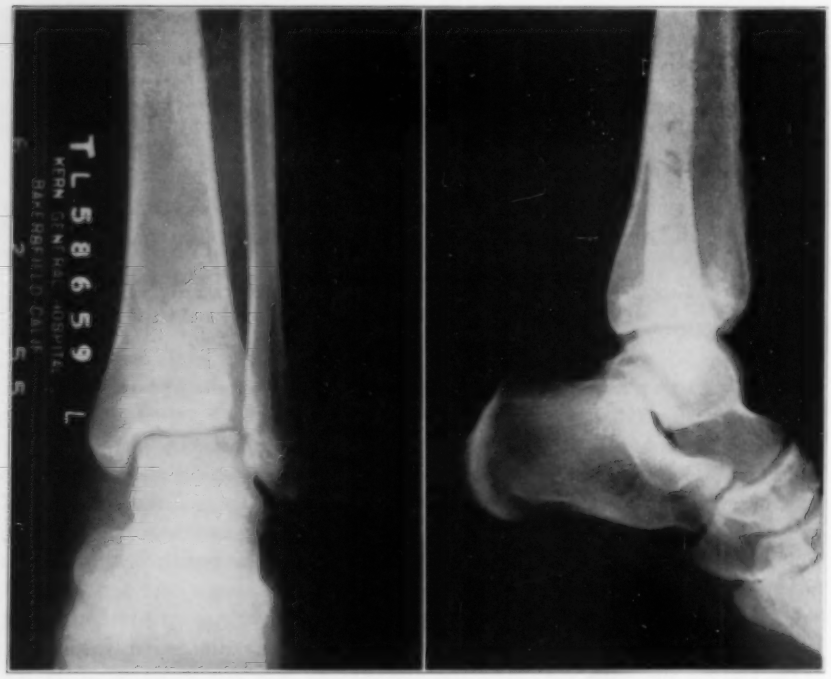


FIG. 1-A

C. R. M. Initial roentgenograms of the left ankle made on June 2, 1955. The left ankle was inflamed, swollen, and tender. Periosteal reaction and destruction are seen in the lateral projection on the anterior surface of the tibia near the ankle joint.

death, her widower married the next younger sister, and they had a child who was at the same time a cousin and a half-sister of C. R. M.'s child.

C. R. M. was born in 1939 and died in 1957 as the result of a Ewing tumor of the tibia that was diagnosed in 1956 after a previous biopsy specimen in 1955 had not been correctly diagnosed.

C. R. M. came to the Emergency Room of the Kern County General Hospital on May 2, 1955, complaining of the sudden onset of pain in the left ankle three days previously. The ankle was indurated; it was nine inches in circumference, whereas the right ankle was eight and one-half inches. The temperature was 100 degrees Fahrenheit. The blood-cell count was not remarkable, and the blood sedimentation rate was 39 millimeters (Westergren). A roentgenogram of the ankle (Fig. 1-A) showed destruction and subperiosteal new-bone formation on the anterior aspect of the distal portion of the tibia.

After appropriate antibiotic treatment, biopsy was done by one of us (M. I.) on June 15. The periosteum of the distal portion of the tibia was thickened. The bone was soft on the lateral aspect, with several areas of erosion, and, in this region, mucoid material was found under the periosteum. A cavity filled with firm, rubbery tissue, greyish yellow to purple, resembling pyogenic membrane, was found within the medullary canal; this cavity extended proximally about one inch beyond the area of subperiosteal-bone formation where a window was made. The posterior and medial cortex appeared normal and bled freely.

The material submitted to the Pathology Laboratory included cancellous bone, cartilage, blood clot, and periosteum. The microscopic section (Fig. 1-B) showed so much necrosis, fibrosis, and new-bone formation that the pathologist (R. W. H.) misinterpreted the histological picture as that of chronic sclerosing osteomyelitis with an unusual histiocytic response.

The patient's course for some time after operation failed to occasion review of the slides obtained at the biopsy, and the roentgenograms of the tibia suggested healing. Even a fracture of the involved tibia sustained in a skiing accident in December 1955 appeared to heal normally.

In August 1956 the patient reported to one of us (M. I.) with a soft-tissue mass over the left lateral malleolus. Surgical exploration revealed involvement of the underlying bone. Through the courtesy of Dr. A. W. Eaton we obtained specimens of soft tissue and bone for our files. Sections

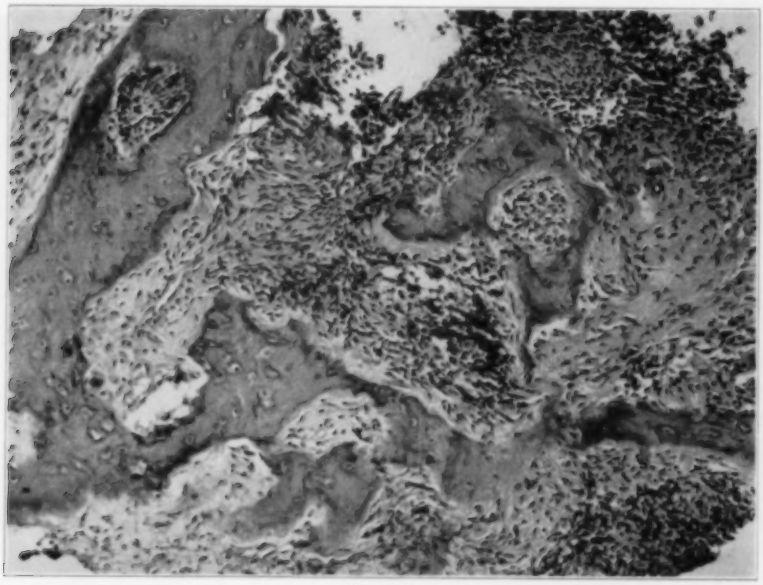


FIG. 1-B

Initial biopsy, June 15, 1955 (× 125).

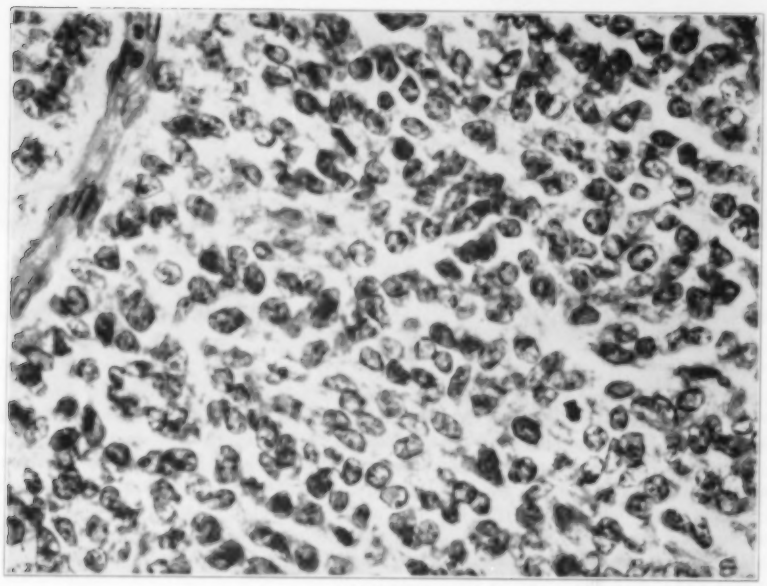


FIG. 1-C

Second biopsy, August 1956 (× 500).

of bone exhibited fibrosis, necrosis, and scattered tumor cells. The soft-tissue mass (Fig. 1-C) was a small-cell tumor, and a diagnosis of Ewing's tumor was made. On review of the previous biopsy specimen (Fig. 1-B), it was thought that this tumor should have been at least strongly suspected the year before.

The patient refused amputation. She was referred to the Los Angeles Tumor Institute, since it was hoped that supervoltage radiation might be more efficacious than conventional voltage. Dr. Hugh Hare summarized her treatment as follows: "The left leg was treated from the knee down from August 24 to September 20, through a port eight by thirty-four centimeters. The 2-mev

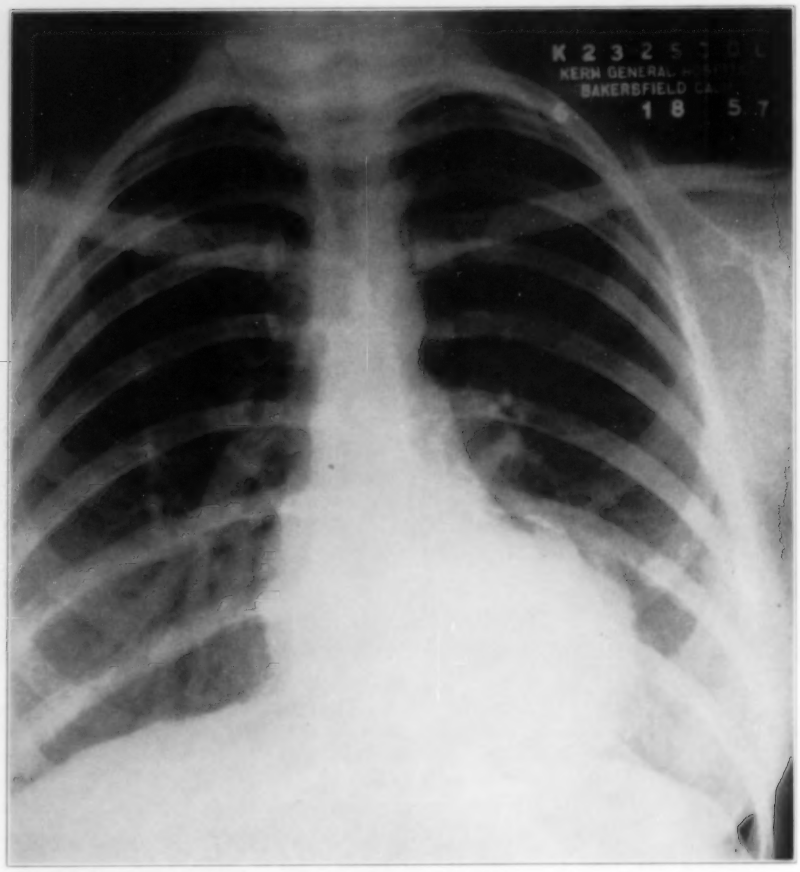


FIG. 1-D

Chest status on June 18, 1957. Metastases behind the heart and in the base of the left lung are evident. The patient had a large metastatic tumor in the left inguinal area and was found to be in about the fourth and one-half month of pregnancy.

machine was used, giving a half-value layer of 12.8 millimeters of copper. The daily dose was 189 r and the total tumor dose was 3,000 r. At the conclusion of this treatment the chest roentgenograms were negative. It was decided to treat the chest prophylactically, and treatment was started through two ports, one anterior and one posterior. After receiving only 375 r to the thorax the patient discontinued treatment, evidently in the belief that she had been cured by a traveling evangelist."

Considerable effort to locate the patient during November and December of 1956 proved fruitless. She next appeared in the Emergency Clinic on June 18, 1957, four and one-half months pregnant and with a huge mass in the left groin. Biopsy revealed metastatic Ewing's tumor. A chest roentgenogram (Fig. 1-D) showed multiple metastases. Cobalt-60 teletherapy was given between July 3 and August 3, 1957, in the following doses expressed in gamma roentgens:

Area	Air Dose	Skin Dose	Tumor Dose	Total Dose to Chest
Anterior aspect of proximal portion of left thigh	5,244	4,715	3,979 at 5-centimeter depth	4,008 at 10-centimeter depth
Lateral aspect of left side of chest	5,092	4,589		
Anterior aspect of left side of chest	304	274		
Posterior aspect of left side of chest	2,028	1,824		

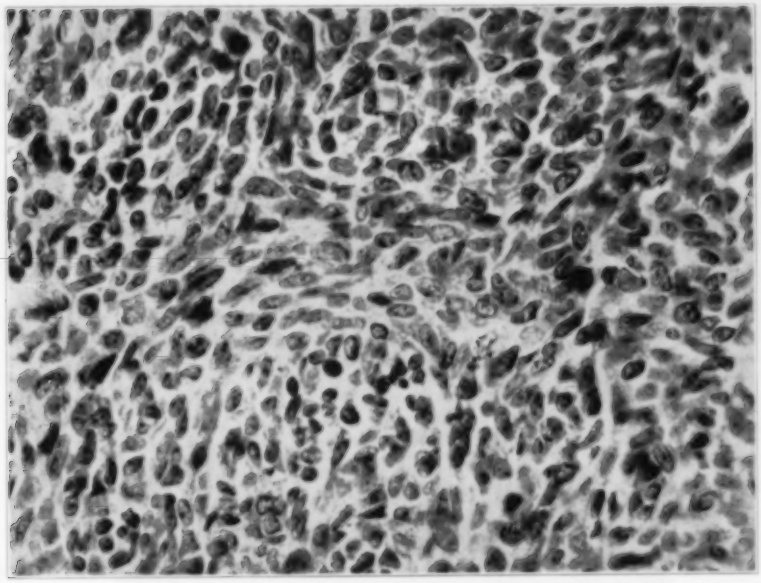


FIG. 1-E

Autopsy specimen, showing the metastases to the liver (× 500).

On completion of this course of therapy the mass in the left thigh had been reduced to less than one-third of its original size. The chest lesions had essentially resolved except for the large metastatic lesion behind the heart on the left, which had been reduced to one-third of its original size. By the end of August, regrowth of the original lesion in the ankle was noted, together with several new metastatic lesions, including one in the left popliteal area and another in the right side of the chest. The patient was most eager to live long enough to leave a viable child. She received repeated transfusions and, in the hope of slowing down the growth and toxicity of the tumor, further cobalt-60 teletherapy was given as follows between August 20 and September 30, 1957. The total doses are given in gamma roentgens:

Area	Port	Air Dose	Skin Dose	Tumor Dose
Lateral aspect of right side of chest	9 by 10 centimeters	4,250	3,820	2,550 as calculated tumor dose in 32 days
Lateral aspect of left ankle	6 by 10 centimeters	3,230	2,900	2,360 as calculated tumor dose in 27 days
Lateral aspect of left popliteal fossa	6 by 10 centimeters	3,000	2,700	2,200 as calculated tumor dose in 26 days

Moderate reduction in the size of the masses was achieved.

C. R. M.'s final admission was on October 1, 1957. She died on October 4 after delivery of a premature viable female infant. Autopsy (PM 273-57) by Dr. Eric Joslin showed Ewing's tumor with metastases in the lungs, liver, colon, brain, pleura, and subcutaneous tissue; infected hydronephrosis; acute pyelonephritis; intraventricular hemorrhage; bronchopneumonia; and right hemothorax. The adrenal glands and the retroperitoneal area were free of tumor. The metastases in the liver showed somewhat elongated cells (Fig. 1-E) with a suggestion of fascicular pattern. Elsewhere the pattern was that of round cells with a suggestion of pseudopapillary structure.

M. J. E., who was born in 1934, came to Kern County General Hospital in August 1953, two weeks before her nineteenth birthday; her pregnancy was close to term, and she had a so-called lump that she had first noted four months previously in the left arm just below the elbow. A roentgenogram (Fig. 2-A) showed destructive and proliferative changes in the radius with elevation of the periosteum. Roentgenograms of the other bones and the chest showed nothing of significance. A high humeral amputation was done on September 4, after a frozen section was reported as showing anaplastic sarcoma.

The gross pathology was described as follows: There is swelling over the head of the radius

with induration of the surrounding tissues. Apparently arising from the upper end of the radius is a tumor measuring approximately twelve by eight by eight centimeters. The tumor is closely applied to the periosteum and widely invades the muscles of the forearm. There is no apparent involvement of the elbow joint or of the tissues above the elbow. Upon sectioning the radius, it is apparent that there is tumor in the medullary cavity. The tumor has also elevated the periosteum in some areas and has penetrated it in others. Where the tumor has invaded the soft tissue it contains no bone on gross inspection. The cortex of the radius is increased in thickness and appears involved with tumor.

FIG. 2-A

M. J. E. The initial roentgenograms made on August 24, 1953, revealing the lesion in the left radius causing the periosteal reaction in the proximal portion of the shaft and the early moth-eaten appearance in the medullary canal.

Figure 2-B is a microphotograph of the tumor. With some histological naïveté the pathologist (R. W. H.) reported the permanent sections as showing anaplastic sarcoma. However, he was forced to concur with the opinion of the consultants [2,20,27], who pointed out the epithelial characteristics of the tumor.

The patient was delivered of a male infant on September 27, 1953. A second child was born on January 20, 1955. Because it was believed that the care of more than two infants would be difficult for a mother with one arm, tubal ligation was done January 26. Thereafter, repeated examinations of the patient showed nothing of note; a roentgenogram of the chest was negative on April 14, 1958. In November 1958 she was interviewed by one of us (R. W. H.) and reported herself in the best of health.

Repeated re-examinations of the original slides did not prove illuminating. It was then decided that the tentative diagnosis of metastatic carcinoma would have to be abandoned, since nothing had developed that could be interpreted as either a primary tumor or a further metastatic lesion.

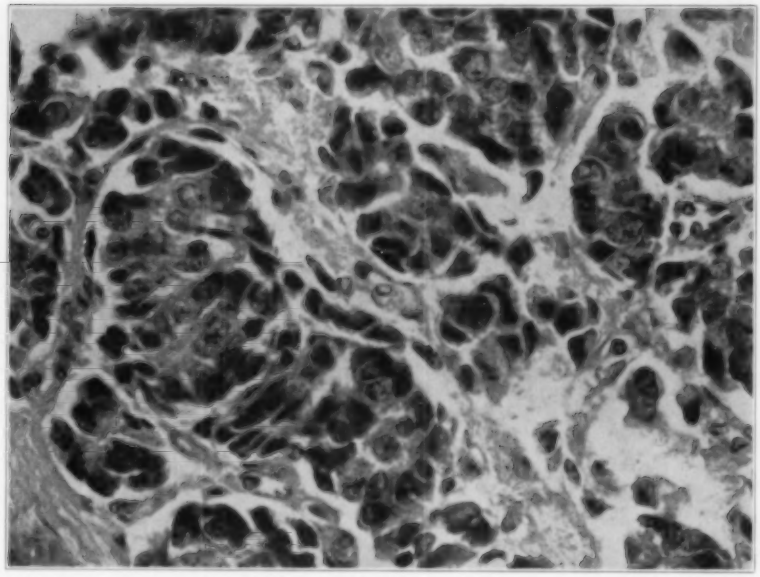


FIG. 2-B

Tumor in the radius, 1953 (× 500).

Dr. Dahlin was kind enough to proffer the opinion of himself and Dr. Dockerty that this was not an adamantinomatoid tumor. He commented on the highly malignant appearance of the tumor and expressed surprise, which many of us had felt, that a patient with such a tumor should have survived for five years.

In February 1959, the patient began to complain of chest pain, and a roentgenogram showed obscuration of the right base of the lung with blunting of the costophrenic angle. The patient moved to another community at this time and was not seen again until May 11. On May 18, a round opacity was visible in the right lower lobe in a roentgenogram of the chest (Fig. 2-C). Bronchoscopy showed mucosal erythema, and a bronchoscopic biopsy was reported to show chronic bronchitis. Thoracotomy was done July 1, 1959. Most of the tissue was removed from the right lower lobe.

Of the several pieces of spongy tissue, light brown to black, the largest measured 7.5 by 6.0 by 1.5 centimeters. It had shiny membrane on one side and was roughened on the other. Microscopic sections showed tumor composed of small cells having indistinct borders, little cytoplasm, and small, round vesiculated nuclei. The cells were not arranged in any structural pattern. The diagnosis was metastatic anaplastic sarcoma (Fig. 2-D). The difference between the pattern of this tumor and that of the radial lesion, and the resemblance between the pattern of this neoplasm and that of the sister's tumor were striking.

The patient was treated with cobalt-60 with the following dosage (in gamma roentgens):

Area	Port	Air Dose	Skin Dose	Tumor Dose
Anterior aspect of right lower side of chest	10 by 14 centimeters	5,235	6,200	
Posterior aspect of right lower side of chest	10 by 14 centimeters	5,290	6,290	
				6,110 as calculated at the mid-thorax level in 40 elapsed days

At the conclusion of treatment there was considerable diminution in the size of the intrathoracic shadow. However, in December 1959, there was a new shadow in the left side of the chest and a reappearance of the shadow in the right side of the chest. Therefore, 16.6 milligrams of nitrogen mustard was given on January 8, 1960. On March 3, she received one pint of blood. She was readmitted on April 14 for more blood. At that time she had fever, chest pain, and anemia, and roentgenograms showed massive shadows in both sides of the chest. At the time of writing she was receiving further x-ray treatment.

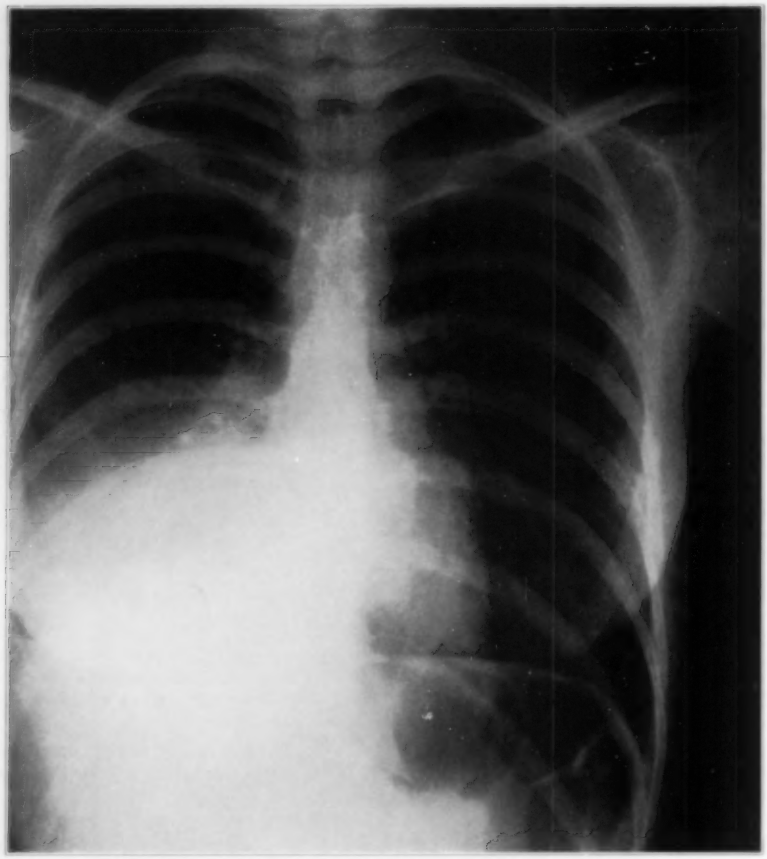


FIG. 2-C

Chest status on May 18, 1959. At this time the patient was acutely ill with fever, cough, and pain in the right side of the chest. The metastatic tumor is seen in the base of the right lung with tumor implants in the pleura causing the pleuritic reaction.

DISCUSSION

The history of C. R. M., the inguinal and popliteal metastases, the absence of an adrenal or retroperitoneal tumor at autopsy, and the evidently metastatic character of the tumor in the thorax all indicate that the primary lesion was in the left ankle. Although at the time of the second biopsy the tumor appeared to be growing with less restraint in soft tissue than in bone, such a finding is not uncommon in so-called Ewing's tumor [10, 11, 21]. The tumor was present in bone, and it seems likely that it started there. Two consultants [3, 20] concurred unreservedly in the diagnosis of Ewing's tumor.

Stout [24] questioned whether Ewing's tumor can always be sharply separated from reticulum-cell sarcoma of bone, and when consulted he expressed some uncertainty [27] as to which term was most appropriate for this particular lesion. His final conclusions on this case are of considerable interest, and he has kindly permitted us to quote them [27]: "I have restudied this case with the aid of trichrome, Laidlaw, and mucicarmine stains. They are very illuminating. The sections (S-1393-55) made on the bone fragments show the tumor cells in small cords and clusters in the marrow spaces. They are embedded in fibroblastic tissue and most of them are small and degenerate; only occasionally can a small group be

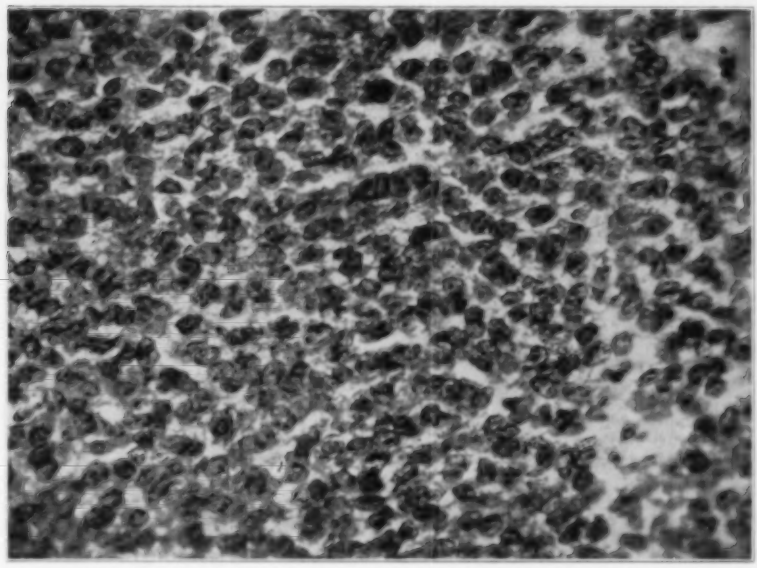


FIG. 2-D
The pleural tumor, 1959 (× 500).

found where the cells are better preserved and larger. Because the small degenerate tumor cells are embedded in fibrous tissue, one cannot tell from the fiber stains whether or not there are reticulin fibers formed in connection with them. But the few groups of better preserved larger cells show no reticulin fibers formed by the tumor cells. This is also true in S-1798-56 and P 273-57. In both of these the tumor cells are relatively large and form masses that for the most part show no evidence of reticulin-fiber formation. Almost everywhere the cells are rounded, and it is only in the metastasis to the liver that some of them are slightly ellipsoidal. This tumor, therefore, because it forms no reticulin fibers at all, has to be classified as a Ewing sarcoma instead of a reticulum-cell sarcoma. It differs from most Ewing sarcomata because of the relatively large size of the cells and their relatively good preservation, both of which features are not ordinarily found in Ewing's sarcoma. To me, this suggests that there is a real link between Ewing's sarcoma and reticulum-cell sarcoma. I believe that both are derived from reticuloblasts and simply represent different stages of cellular differentiation."

Without substantial new data there seems no point in reviewing the long controversy concerning the term Ewing's tumor [5,9,10,11,12,16,17,24,29]. It remains a convenient eponym for one or more groups of tumors, apparently primary in bone, that fail to produce neoplastic structures definitely reminiscent of either bone matrix or bone marrow. The tumors so designated are further characterized by small to medium-sized tumor cells of somewhat undifferentiated aspect, not consistently associated with significant amounts of reticulin. Nevertheless, comparative studies of so-called Ewing's tumor and reticulum-cell sarcoma and the recorded difficulties in the differential diagnosis between Ewing's tumor and osteomyelitis [10,11] and between Ewing's tumor and histiocytosis [21] suggest strongly that some Ewing's tumors are derived from reticuloblasts or histioblasts. The possibility that others might be derived from intra-osseous neural elements [28,29] can hardly be evaluated without tissue-culture studies [22]. The diagnostic problems presented by M. J. E.'s tumor have already been indicated. For a summary of these problems we are fortunate to be able to quote Dr. Stout:

"The original tumor in the radius (S 1870-53, P&S 43142) I have restudied with the aid of trichrome and Laidlaw stains. The tumor consists of cords and balls of quite large rounded cells that are separated by slender fibrovascular septa in a fashion that certainly looks very much like an epithelial growth. As far as I can make out, I do not think these cells form any reticulin fibers, although occasionally a very delicate fiber is found among them. The cells further sometimes tend to be so arranged that their nuclei are kept apart by cytoplasmic bulging. In the cords this sometimes gives a false impression of pseudotube formation, and in the balls a false pseudorosette results. These arrangements add to the resemblance of the tumor cells to epithelial formations.

"The tissue from the lung, S-2181-59 (P&S 64060) is quite different. Gone are the cords and balls, the pseudorosettes and pseudotubes. The tumor cells are smaller, they form large sheets with a widely scattered framework, and there are reticulin fibers among the cells in some places, while in others there are no fibers among the cells. This tumor in the lung is so different from the tumor in the radius that one wonders if there are two independent tumors or if the lung tumor is a metastasis from the radius.

"The almost epithelial appearance of the tumor in the radius raised the question of metastatic carcinoma when it was first studied. It seems now that this is very unlikely because in six years no primary focus has declared itself. The only other malignant epithelial tumor primary in a long bone to be considered is the so-called adamantinoma. . . .

"If this tumor in the radius is an adamantinoma it seems impossible to believe that the tumor in the lung is a metastasis from it. We would have to believe that the lung tumor is a good deal like the sister's tumor, that is, a variant of Ewing's sarcoma. But if that is the case, it must be metastatic from some place in a bone, and the only known site of bone tumor in M. J. E. is in the radius. Can we believe that the tumor in the radius is a peculiar variant of a Ewing tumor? It is different from any Ewing tumor I have ever seen or read of, but it seems to me that the least objectionable hypothesis is to suppose that it is a unique variant of a Ewing sarcoma with metastasis to the lung."

This conclusion would seem to be the hypothesis most readily compatible with the assumption of some biological similarity between these sisters' tumors *. Certainly, the epithelial characteristics of M. J. E.'s lesion in the radius do not force us to assume that it was derived either from cutaneous ectoderm or from entoderm [6,14,15,25,26,27,28].

Unless the case of M. J. E. is actually unique, it might be important, particularly in a young person, to bear in mind the possibility that a bone tumor which appears to be metastatic may actually be primary.

SUMMARY AND CONCLUSIONS

The younger of two sisters (C. R. M.) died at the age of nineteen years with extensive metastases from a tumor in the lower portion of the tibia that was evidently a Ewing sarcoma. The older sister (M. J. E.) had a high humeral amputation for a tumor of the radius at the age of nineteen years. Because of its histological appearance, this tumor was at first suspected of being metastatic carcinoma. Because the patient remained well for five years, however, this notion was abandoned. During the sixth year there developed in M. J. E. a pleural and pulmonary tumor that is interpreted as a metastasis from the radial lesion. The pattern of this secondary tumor lacks epithelial features and resembles that

* Dr. Louis Lichtenstein [20] was also kind enough to review relevant sections of M. J. E.'s tumor. He will only say that he considers it very puzzling.

of the younger sister's tumor. We feel that the most tenable diagnosis for M. J. E.'s tumor is that it is an unusual variant of Ewing's tumor.

REFERENCES

1. Ayres, W. W., and Silliphant, W. M.: Charcot-Leyden Crystals in Eosinophilic Granuloma of Bone. Am. J. Clin. Pathol., **30:** 323–327, 1958.
2. Bennett, G. A.: Personal communication.
3. Budd, J. W.: Personal communication.
4. Changus, G. W.; Speed, J. S.; and Stewart, F. W.: Malignant Angioblastoma of Bone. A Reappraisal of Adamantinoma of Long Bone. Cancer, **10:** 540–559, 1957.
5. Coley, B. L.; Higinbotham, N. L.; and Bowdin, Lemuel: Endothelioma of Bone (Ewing's Sarcoma). Ann. Surg., **128:** 533–560, 1948.
6. Comess, M. S.; Dockerty, M. B.; and Beahrs, O. H.: Cryptic Cervical Nodal Metastases: A Pathologic Study of Possible Primary Sources. Arizona Med., **15:** 87–95, 1958.
7. Dahlin, D. C.: Personal communication.
8. Dockerty, M. B.: Personal communication.
9. Foote, F. W., Jr., and Anderson, H. R.: Histogenesis of Ewing's Tumor. Am. J. Pathol., **17:** 497–502, 1941.
10. Geschickter, C. F., and Copeland, M. M.: Tumors of Bone. New York, American Journal of Cancer, 1931.
11. Geschickter, C. F., and Maseritz, J. H.: Ewing's Sarcoma. J. Bone and Joint Surg., **21:** 26–39, Jan. 1939.
12. Jaffe, H. L.: Tumors and Tumorous Conditions of Bones and Joints. Philadelphia, Lea and Febiger, 1958.
13. Kern County General Hospital Tumor Board: Unpublished observations.
14. Kernohan, J. W., and Sayre, G. P.: Tumors of the Central Nervous System, Section X—Fascicle 35, Atlas of Tumor Pathology. Washington, D. C., Armed Forces Institute of Pathology, 1952.
15. Kernohan, J. W., and Sayre, G. P.: Tumors of the Pineal Body. Section X—Fascicle 37, Atlas of Tumor Pathology. Washington, D. C., Armed Forces Institute of Pathology, 1952.
16. LeCompte, P. M.: Tumors of the Carotid Body and Related Structures (Chemoreceptor System). Section IV—Fascicle 16, Atlas of Tumor Pathology. Washington, D. C., Armed Forces Institute of Pathology, 1951.
17. Lichtenstein, Louis: Bone Tumors. Ed. 2. St. Louis, The C. V. Mosby Co., 1959.
18. Lichtenstein, Louis, and Jaffe, H. L.: Ewing's Sarcoma of Bone. Am. J. Pathol., **23:** 43–67, 1947.
19. Lichtenstein, Louis: Histiocytosis X: Integration of Eosinophilic Granuloma of Bone, "Letterer-Siwe-Disease," and "Schüller-Christian Disease" as Related Manifestations of a Single Nosologic Entity. A.M.A. Arch. Pathol., **56:** 84–102, 1953.
20. Lichtenstein, Louis: Personal communication.
21. McCormack, L. J.; Dockerty, M. B.; and Ghormley, R. K.: Ewing's Sarcoma. Cancer, **5:** 85–99, 1952.
22. Murray, M. R., and Stout, A. P.: Distinctive Characteristics of the Sympathico-blastoma Cultivated in Vitro. Am. J. Pathol., **23:** 429–442, 1947.
23. Steiner, P. E.: Cancer: Race and Geography. Baltimore, The Williams and Wilkins Co., 1954.
24. Stout, A. P.: A Discussion of the Pathology and Histogenesis of Ewing's Tumor of Bone Marrow. Am. J. Roentgenol., **50:** 334–342, 1943.
25. Stout, A. P.: Tumors of the Peripheral Nervous System. Section II—Fascicle 6, Atlas of Tumor Pathology. Washington, D. C., Armed Forces Institute of Pathology, 1949.
26. Stout, A. P.: Tumors of Soft Tissues. Section II—Fascicle 5, Atlas of Tumor Pathology. Washington, D. C., Armed Forces Institute of Pathology, 1953.
27. Stout, A. P.: Personal communication.
28. Wilber, M. C., and Woodstock, J. A.: Ganglioneuromata in Bone. Report of a Case. J. Bone and Joint Surg., **39-A:** 1385–1388, Dec. 1957.
29. Willis, R. A.: Metastatic Neuroblastoma in Bone Presenting the Ewing Syndrome, with a Discussion of "Ewing's Sarcoma". Am. J. Pathol., **16:** 317–332, 1940.
30. Willis, R. A.: Teratomas. Section III—Fascicle 9, Atlas of Tumor Pathology. Washington, D. C., Armed Forces Institute of Pathology, 1951.
31. Willis, R. A.: Pathology of Tumours. Ed. 2. St. Louis, The C. V. Mosby Co., 1953.

Unilateral Laminar Joints of Lumbar Spine

Case Report

BY MALCOLM D. JONES, M.D., MONTREAL, QUEBEC, CANADA

From the Department of Radiology, Montreal Neurological Institute, Montreal

Defects in the posterior arches of the vertebrae have been attributed to failure of union of normal ossification centers and to the presence of anomalous fibrous zones in portions of the arch normally occupied by a single ossification center (spondylolysis)[1,2,6,7,8,9,10]. The present report describes two anomalous true joints in one of the laminae of the third lumbar vertebra.

The specimen, which had been preserved in formalin solution, was one of several spines collected by Doctor D. L. McRae of the Department of Radiology of the Montreal Neurological Institute. Unfortunately, no clinical data were available. The appearance of the vertebrae indicated that the spine was that of a male about twenty-five to thirty years of age. Prior to dissection, routine lateral, anteroposterior, and oblique roentgenograms were obtained. These initial views revealed an atypical spondylolysis of the third lumbar vertebra, located in the left lamina between the base of the spinous process and the pedicle (Fig. 1-A). After section of the pedicles and removal of the vertebral bodies, roentgenograms were made of the posterior elements in the standard oblique projection. These roentgenograms showed two separate joints located side by side in the mid-portion of the left lamina (Fig. 1-B). The articular surfaces of these joints were

Fig. 1-A

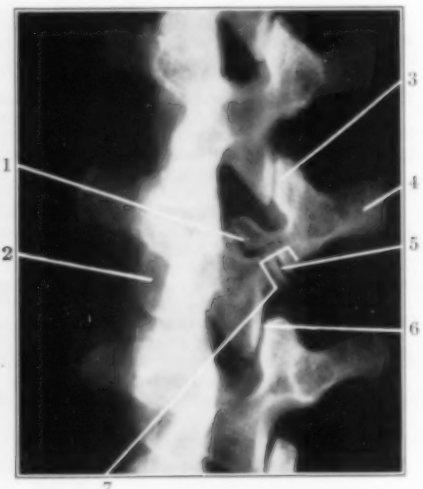


Fig. 1-B

Fig. 1-A: Oblique roentgenograms of the specimen showing the defects in the lamina of the third lumbar vertebra. The medial defect is partially obscured by the base of the spinous process. The subarachnoid space shows residual contrast material from previous myelographic studies, which failed to show abnormalities in this region.

Fig. 1-B: Oblique roentgenograms of the posterior elements after section of the pedicles and removal of the bodies. The two defects in the left lamina of the third lumbar vertebra are clearly visualized. The positioning of the specimen is the same as that for a standard left posterior oblique roentgenogram. The left transverse processes are to the viewer's right. (Key: 1, medial anomalous joint; 2, spinous process of third lumbar vertebra; 3, superior articular facet of third lumbar vertebra; 4, transverse process of third lumbar vertebra; 5, lateral anomalous joint; 6, inferior articular facet of third lumbar vertebra; and 7, area resected for pathological examinations.)

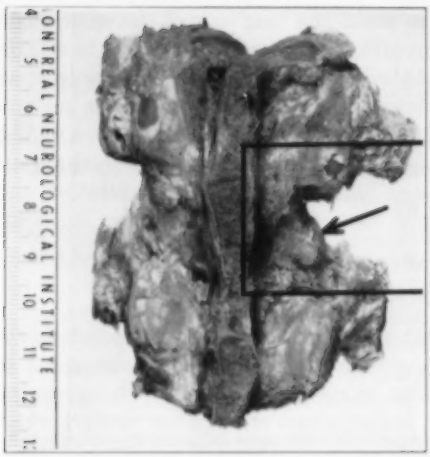


FIG. 2-A

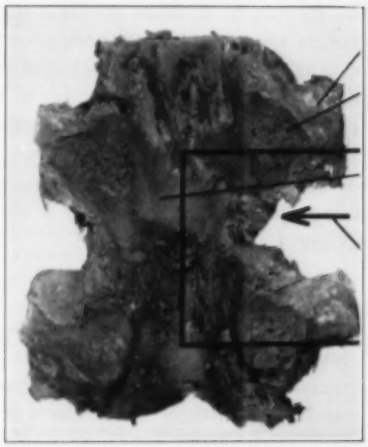


FIG. 2-B

Fig. 2-A: Dorsal view of the lamina of the third lumbar vertebra with the apophyseal joints intact at both the upper and lower articulations. The spinous processes have been resected. The arrow points to the lateral anomalous joint in the left lamina of the third lumbar vertebra.

Fig. 2-B: Ventral view of the same portion of the specimen showing the anomalous joints in the lamina between the pedicle and the base of the spinous process. The spinous process is not visualized here since it is on the dorsum of the specimen directly behind the vertical line. Neither the neural foramen nor the spinal canal was encroached upon by this joint. (Key: 1, transverse process of third lumbar vertebra; 2, resected pedicle of the third lumbar vertebra; 3, lamina of third lumbar vertebra; and 4, lateral anomalous joint.)

FIG. 3

Photomicrograph of histological preparation showing well formed articular cartilage.

outlined by typical subchondral bone. A section of the more lateral of the two joints was removed for microscopic study (Fig. 1-B). When the soft tissues had been dissected off these joints (Figs. 2-A and 2-B) each joint was found to have a separate capsule attached firmly to the lamina at the margins of the articular surfaces. The joints were separated from each other by a complete defect through which a fine probe could be passed. On probing, the joint surfaces were found to have the consistency of hyaline articular cartilage. When torque was applied to

the specimens so as to produce rotation about the long axis of the spine slight motion was observed at these anomalous articulations sufficient to produce slight malalignment of the adjacent margins of the lamina on each side of the anomalous joints. The microscopic sections of the lateral joint showed the opposing surfaces to be covered with what was considered to be hyaline articular cartilage, a finding that indicates that these were true joints (Fig. 3). Unfortunately, the histological sections of the joint capsule were destroyed during the process of preparation, and it is impossible to determine if this joint had a true synovial lining and joint capsule.

DISCUSSION

According to Willis [11], 5 to 7 per cent of lumbar vertebrae have defects in the lamina which are usually fibrous zones in the bony arch. The occurrence of anomalous true joints in the laminae must be rare; no report of such a joint has been located. Roche [7] described a defect in the lamina of a lumbar vertebra which was surrounded by accessory slips of ligamentum flavum and contained a space between the adjacent bone surfaces. Cartilage was not described as covering the bone surfaces, however.

The embryology of joints was described by Haines and summarized by Collins. Although it would appear that the process of joint formation could occur at any point in the growing skeleton, the organizer which predetermines the location of joint development does not, normally, exist in the lamina of the vertebra. It is possible that aberrant or residual organizer material in the mid-portion of the lamina might have caused the present defect. Although the roentgenographic appearance of the defects is not unlike that of an old, ununited fracture, the two adjacent well formed and separate medial and lateral joints with individual capsules and typical hyaline cartilage covering the adjacent bone surfaces could best be explained as anomalous joints. The fibrous defects of obscure origin that are found in the lamina at this location are filled with fibrous tissue which binds the two fragments of the lamina together. In the case here reported, no connection between the bone margins existed except for the capsules. The location of the joints was such that overdevelopment of either the mammillary process or the accessory process could not have produced such an anomaly. Dr. Gordon Mathieson of the Montreal Neurological Institute reviewed the sections of the lateral joint and described the cartilage as typical articular cartilage.

NOTE: The anatomical material provided by Dr. Donald McRae, Chief of the Department of Radiology, Montreal Neurological Institute, and the histological preparations by Dr. Gordon Mathieson of the Department of Pathology are gratefully acknowledged.

REFERENCES

1. BISTROM, O.: Congenital Anomalies of Lumbar Spine of Persons with Painless Backs. Ann. Chir. et Gynaec. Fenniae, **43:** 102–115, 1954.
2. BRAILSFORD, J. F.: The Radiology of Bones and Joints, p. 274. Baltimore, William Wood and Co., 1934.
3. COLLINS, D. H.: Pathology of Articular and Spinal Diseases, pp. 4–6. London, Edward Arnold and Co., 1946.
4. FELL, H. B., and CANTI, R. G.: Experiments on the Development *in vitro* of the Avian Knee-Joint. Proc. Roy. Soc. London, ser. B., **116:** 316–351, 1934.
5. HAINES, R. W.: The Development of Joints. J. Anat., **81:** 33–35, 1947.
6. ROCHE, M. B.: The Incidence of Separate Neural Arch and Coincident Bone Variations; Survey of 4,200 Skeletons. Anat. Rec., **109:** 233–252, 1951.
7. ROCHE, M. B.: The Pathology of Neural-Arch Defects. A Dissection Study. J. Bone and Joint Surg., **31-A:** 529–537, July 1949.
8. ROWE, G. G.: Anomalous Vertebrae from the Lumbosacral Column of Man. Anat. Rec., **107:** 171–179, 1950.
9. WILLIS, T. A.: An Analysis of Vertebral Anomalies. Am. J. Surg., **6:** 163–168, 1929.
10. WILLIS, T. A.: The Separate Neural Arch. J. Bone and Joint Surg., **13:** 709–721, Oct. 1931.
11. WILLIS, T. A.: Man's Back, p. 38. Springfield, Charles C. Thomas, 1953.

Slipped Capital Femoral Epiphysis in Negroes

A Study Of Ninety-five Cases *

BY CAESAR OROFINO, M.D., JOHN J. INNIS, M.D., AND CEDRIC W. LOWREY, M.D.,
NEW ORLEANS, LOUISIANA

From the Department of Orthopaedic Surgery, Ochsner Clinic, the Division of Orthopaedic Surgery, Tulane University, and the Orthopaedic Surgery Service, Tulane Unit, Charity Hospital, New Orleans

In an analysis of his cases of slipping of the upper femoral epiphysis Howorth wrote, "The lesion always heals spontaneously, and treatment is of no value unless it produces a better result than would have been accomplished by nature. Too many reports of the results of treatment of this disease have failed to take these

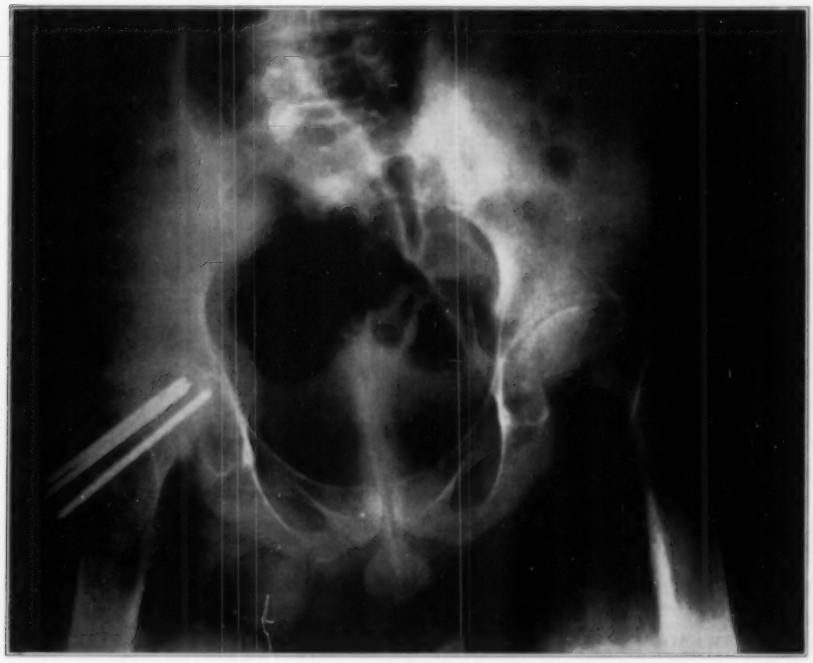


Fig. 1

Twelve-year-old Negro child had had cuneiform osteotomy of the right hip one year previously. He complained of pain in both hips. Surgery on the left hip was refused by the child's mother. Both hips show similar degeneration without evidence of vascular involvement.

facts into consideration. The results in many cases which had no treatment have been better than those in similar cases after operation."

The commonly accepted concept of the natural history of a hip with slipping of the upper femoral epiphysis is that it is a progressive mechanical disruption of the joint due to postero-inferior slipping of the head of the femur, with resulting limitation of motion and shortening of the extremity. If the slipping is untreated and not reduced, it is believed to cause degenerative arthritis of the hip in middle life. Degeneration of the hip joint with pain, limitation of motion, and restriction of activities during adolescence and shortly after puberty is mentioned as occurring

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 28, 1960.

TABLE I

RESULTS OF TREATMENT OF ACUTE SLIPPED CAPITAL FEMORAL EPIPHYSIS IN ELEVEN HIPS

Treatment	Degree of Slipping	No. of Results Satisfactory	No. of Results Unsatisfactory
Closed reduction and internal fixation	$> \frac{1}{3}$	6	2
	$< \frac{1}{3}$	0	0
Closed reduction and spica	$> \frac{1}{3}$	0	1
Spica without reduction	$< \frac{1}{3}$	0	1
In situ nailing *	$< \frac{1}{3}$	1	0
Totals		7	4

* Smith-Petersen

TABLE II

RESULTS IN TWENTY HIPS WITH SLIPPED CAPITAL FEMORAL EPIPHYSES WHICH HAD NO TREATMENT

Degree of Slipping	No. of Results Satisfactory	No. of Results Unsatisfactory
$> \frac{1}{3}$	0	17
$< \frac{1}{3}$	0	3
Totals	0	20

only as a complication of treatment and not as a finding in the untreated hip. In those cases reported in the literature, good results were obtained by Howorth in all patients after his bone-pegging procedure. Klein and associates reported 96 per cent of true normal function of the hip after nailing *in situ* and 92 per cent of normal function for hips nailed after open reduction. Hall found the over-all satisfactory results to be 77.9 per cent. In only one series of cases was there any mention of race, but no indication was given about the fate of the hips of the Negro patients [4]. For many years it has been a clinical observation of the attending staff of Charity Hospital that, in general, the results of treatment of slipped capital femoral epiphysis in Negroes were far more unsatisfactory than the results reported in the orthopaedic literature, where no differentiation is made in regard to race.

In an attempt to determine the functional status of the hips of Negroes after slipping of the capital femoral epiphysis at puberty, the records at Charity Hospital during the past twenty years were examined. The records of ninety-five Negro patients treated for slipped capital femoral epiphysis were complete enough to permit review. Of these ninety-five patients, thirty-two had bilateral slipped epiphysis, so that this study included a total of 127 hips. None of the patients was observed after adolescence; hence, all results represent the fate of these hips before the patient was eighteen years old. In evaluating the results, a hip was considered to have a satisfactory result if the patient had a painless, stable hip with perhaps some limitation of motion and some shortening of the extremity. The result was classified as unsatisfactory if the patient had pain severe enough to cause limitation of activity and to necessitate continued medical care. It was not the purpose of this study to compare the results of different methods of treatment, but rather to attempt to determine whether slipping of the capital femoral epiphysis in Negroes is more serious and more disabling than it is in Caucasians.

Hips with a history of trauma and roentgenographic evidence of extreme displacement were classified as acute slips and separated from the remainder of the cases. Inasmuch as most of these hips were treated by manipulation and fixation, it was believed that their inclusion with other hips with chronic slipped epiphyses might warrant the justifiable criticism that manipulation of the hip forceful enough

TABLE III

RESULTS IN FIFTY-ONE HIPS WITH SLIPPED CAPITAL FEMORAL EPIPHYSES TREATED BY *in Situ* FIXATION

Degree of Slipping	No. of Results	
	Satisfactory	Unsatisfactory
$>\frac{1}{3}$	0	2
$<\frac{1}{3}$	40	9
Totals	40	11

TABLE IV

RESULTS IN THIRTY-THREE HIPS WITH SLIPPED CAPITAL FEMORAL EPIPHYSES TREATED BY CUNEIFORM OSTEOTOMY

Degree of Slipping	No. of Results	
	Satisfactory	Unsatisfactory
$>\frac{1}{3}$	11	22
$<\frac{1}{3}$	0	0
Totals	11	22

TABLE V

TWELVE HIPS WITH SLIPPED CAPITAL FEMORAL EPIPHYSIS TREATED BY MISCELLANEOUS METHODS

Degree of Slipping	No. of Results	
	Satisfactory	Unsatisfactory
$>\frac{1}{3}$	0	6
$<\frac{1}{3}$	1	5
Totals	1	11

to result in reposition of the femoral head might have caused various vascular changes and thus influenced the end result. In this series there were ten such patients with eleven hips involved (Table I). Two of these eleven hips in two patients were treated in plaster spicas, one with and the other without manipulative reduction. When last examined both of these patients had pain and limited motion of the hip; both were classified as having unsatisfactory results. Of the remaining nine hips, eight had closed reduction and internal fixation with heavy threaded wires. The other hip was fixed *in situ* by a Smith-Petersen nail. In these nine hips, the results were satisfactory in seven, and unsatisfactory in two.

The remaining eighty-five patients, with 116 hips involved, were divided into four main subdivisions. The first group of twenty hips was classified as having had no treatment. This group consisted of patients who were first seen after closure of the epiphyseal line or who were not seen during the period that their epiphyses were closing. Also included were those patients who had had subtrochanteric osteotomy or cup arthroplasty, since these salvage procedures were performed only after closure of the epiphysis had occurred. In all twenty hips in this group the results were unsatisfactory (Table II). Pain in the hip, limitation of motion, and degeneration of the hip joint had developed by the time these untreated patients were eighteen years of age. This is in pronounced contrast to the commonly accepted concept of this disease, in which degenerative arthritis, apparently of mechanical origin, is a late complication of middle age.

The second group of fifty-one hips consisted of patients who had been treated by internal fixation *in situ* by a Smith-Petersen nail, threaded Steinmann pins, or Howorth peg-grafts. This method of treatment, in general, had been reserved for hips in which the femoral head had slipped less than one-third the diameter of the

FIG. 2-A

FIG. 2-B

Figs. 2-A and 2-B: Eleven-year-old Negro girl had pain in the left hip, restriction of motion, and limp of increasing severity for nine months. Preoperative roentgenograms show a slipped epiphysis and narrowing of the left hip.

femoral neck. Results were satisfactory in forty hips and unsatisfactory in eleven (Table III).

The third group consisted of patients in whom the slip was greater than one-third of the diameter of the femoral neck and who had been treated by cuneiform osteotomy with replacement of the femoral head in anatomical relationship to the neck. In the thirty-three hips in this group, the results were satisfactory in eleven and unsatisfactory in twenty-two (Table IV).

The fourth group included patients treated by miscellaneous methods, including traction without weight-bearing, immobilization in plaster, or attempted closed reduction of chronic slipped epiphysis followed by immobilization in a spica cast. None of these methods is now being employed at this institution. In the twelve hips in this group, the results were unsatisfactory in eleven (Table V).

DISCUSSION

Of the 116 hips with chronic, slipped, capital femoral epiphyses, only fifty-two were not causing incapacitating pain by the time the patients were eighteen years of age. The most frequent roentgenographic observation associated with the disabling pain was degeneration of the hip joint. All these hips showed a great decrease in the range of both active and passive motion. The fact that this is a complication of the condition in these patients rather than a complication of treatment is substantiated by the bad results in the twenty hips that received no treatment before closure of the epiphyseal line. In all twenty of these untreated hips limitation of motion and incapacitating pain had developed before the patient was eighteen years of age. Further studies are being planned to correlate the histological changes about the hip joint in this disease, the roentgenographic evidence, and the functional end result. The results of this study are at variance with the findings of others since these results indicate that in the Negro early degeneration of the hip after slipping of the capital femoral epiphysis—that is, degeneration which occurs shortly before puberty—is frequently not a complication of treatment.

SUMMARY

The records of ninety-five Negroes with slipped capital femoral epiphyses treated at the Charity Hospital in New Orleans were reviewed in an attempt to assay the validity of the clinical observation of the attending staff at Charity Hospital that the results of treatment of slipped capital femoral epiphysis in Negroes is far more unsatisfactory than the results reported in the orthopaedic literature. Thirty-two of the ninety-five patients had bilateral involvement. In this series of 127 hips, only fifty-nine patients reached the age of eighteen years without incapacitating pain accompanied by degeneration of the joint and limitation of motion. This study indicates that the natural history of the slipped capital femoral epiphysis in a Negro differs from that in a Caucasian in that early degeneration of the joint accompanied by pain and limitation of motion is common, regardless of the method of treatment, and appears to be in direct relationship to the degree of slip.

REFERENCES

1. Cleveland, Mather; Bosworth, D. M.; Daly, J. N.; and Hess, W. E.: Study of Displaced Capital Femoral Epiphyses. J. Bone and Joint Surg. **33-A:** 955–967, Oct. 1951.
2. Hall, J. E.: The Results of Treatment of Slipped Femoral Epiphysis. J. Bone and Joint Surg., **39-B:** 659–673, Nov. 1957.
3. Howorth, H. B.: Slipping of the Upper Femoral Epiphysis. J. Bone and Joint Surg., **31-A:** 734–747, Oct. 1949.
4. Klein, Armin; Joplin, R. J.; Reidy, J. A.; and Hanelin, Joseph: Slipped Capital Femoral Epiphysis, p. 100. Springfield, Illinois, Charles C. Thomas, 1953.

A Rare Subperiosteal Metastasis Eroding the Femoral Cortex Eight Years after Radical Mastectomy for Adenocarcinoma

BY CAPTAIN CHARLES A. BORGIA, *Medical Corps, United States Air Force*

From the Orthopaedic Service, Walter Reed General Hospital, Walter Reed Army Medical Center, Washington, D. C.

The skeleton is one of the most common sites of cancer metastases, although many metastases are not apparent in routine roentgenograms. Abrams, Spiro, and Goldstein found that over 60 per cent of the patients with breast carcinoma had skeletal metastases at autopsy. Clinically, the average time for the appearance of skeletal metastases after diagnosis and treatment of breast carcinoma is six to eighteen months. In exceptional cases, metastases have not developed for five to eight years [7].

Cancer-cell emboli usually reach the skeleton through the blood stream, either arterial or venous. The lymphatics are thought by many to be unimportant in skeletal metastases, since lymphatic channels are apparently absent in bone marrow [4,7]. Once in bone, the viable cancer emboli multiply and usually replace normal marrow cells, with lysis of bone, or the formation of reactive bone, or both changes occurring in relation to the metastatic focus. Generalized skeletal metastases without visceral involvement may occur. This is explained by Batson's vertebral vein system through which cancer emboli may bypass the portal vein system, liver, and lungs. The vertebral vein system, however, is only one of several ways in which metastases can reach bone by a vascular route [3].

Carcinoma of the breast metastasizes to soft tissues principally by the lymphatic route, with approximately 60 per cent of the patients having metastases to the axillary nodes by the time of initial surgery [7]. Visceral metastases are most prominent in the lungs and pleura, with the liver, bone, brain, adrenals, and spleen following in that order of frequency. Metastases to bone are blood borne; they are usually osteolytic, but they may be both osteolytic and osteoblastic. The vertebral spine, pelvis, femur, ribs, and cranial bones represent the sites most commonly involved. Rarely is there involvement below the elbow or the knee. Skeletal metastases from carcinoma of the breast are usually multiple, but a single metastasis is found in about 25 per cent of patients with carcinoma of the breast. The majority of these solitary metastases are in a vertebra or in the proximal part of the femur in the region of the neck and greater trochanter. Classically, the lesions first appear in the medulla and subsequently destroy the cortex from within. Often, mottled, increased density of the bone within the area of destruction is seen, and thickening of the cortex appears above or below the site of metastasis. Histopathological study of bone metastatic lesions shows destruction of both the spongy and cortical bone, apparently by direct contact with tumor cells and by osteoclastic activity. Geschickter and Copeland stated that regardless of how the tumor cells reach the skeleton, they begin to proliferate in the red marrow and spread by way of the medullary cavity and the Haversian canals.

CASE REPORT

A Caucasian woman, forty-three years old, underwent a left radical mastectomy for adenocarcinoma in 1951. This was followed shortly after by a right simple mastectomy for benign cystic

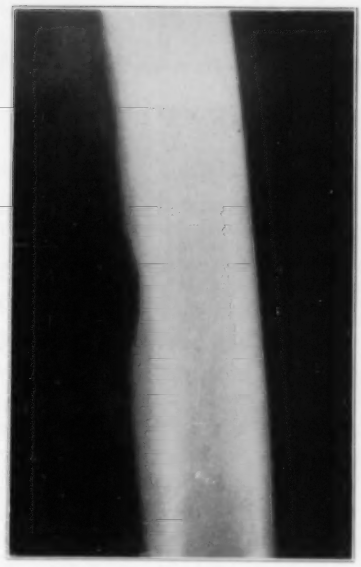


FIG. 1

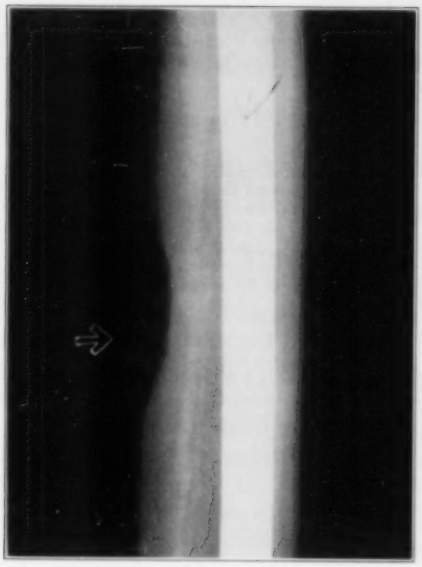


FIG. 2

Fig. 1: Roentgenogram of right femur three months prior to admission to Walter Reed General Hospital. Note the cortical thickening above the lesion.

Fig. 2: Roentgenogram of the right femur shortly after excisional biopsy and prophylactic intramedullary nailing.

disease. She had no further symptoms or treatment and exhibited no hint of metastatic disease until July 1958, eight months before her admission to Walter Reed General Hospital in March 1959. In July she had complained of deep pain in the posteromedial aspect of the middle of her right thigh that had slowly increased in severity over the preceding eight months. Routine anteroposterior and lateral roentgenograms of the femur had been interpreted initially as normal, but oblique films made during arteriography revealed a small area of subperiosteal cortical erosion. The patient denied trauma, weight loss, fatigue, anorexia, or any other symptoms suggestive of metastatic disease. A skeletal survey was not remarkable.

Physical examination, except for well healed mastectomy scars and moderate subjective pain on deep palpation over the posteromedial aspect of the middle of the right thigh, was unremarkable. Laboratory studies were all within normal limits, with no evidence of bone disease.

In late March 1959, the patient underwent excisional biopsy of the femoral lesion. Friable yellowish orange tumor tissue was found at the linea aspera over an area of approximately three by one by two centimeters. The tumor definitely did not extend into the medullary canal. The underlying and surrounding bone was quite hard and grossly normal. Frozen and permanent histological sections established the diagnosis of metastatic adenocarcinoma of the breast. A Küntscher nail was inserted through the greater trochanter, and the patient recovered completely. She was discharged from the hospital after receiving radiation therapy to the site of the lesion. Fifteen months after completion of treatment the patient was free from recurrence of disease.

DISCUSSION

This case is reported because it represents an unusual type of subperiosteal or extracortical metastasis to bone that occurred eight years after radical mastectomy for adenocarcinoma [5,6,7]. No similar lesion could be found in the files at Walter Reed General Hospital or in the files of the Armed Forces Institute of Pathology. In the chapter on metastatic lesions to bone, Jaffe described and illustrated a somewhat similar roentgenogram, showing erosion of the cortex of a femur from the periosteal side by a metastatic epidermoid carcinoma, with the primary site undetermined. In two other cases observed by Jaffe, in which the cortex of the femoral shaft was being eroded from the periosteal side by an

epidermoid carcinoma, the primary tumor was found in the lung. In none of the English-language literature reviewed since 1945, however, was there a description of any single subperiosteal, erosive, cortical metastasis from carcinoma of the breast.

REFERENCES

1. Abrams, H. L.; Spiro, Robert; and Goldstein, Norman: Metastases in Carcinoma. Analysis of 1000 Autopsied Cases. Cancer, **3:** 74–85, 1950.
2. Batson, O. V.: The Function of the Vertebral Veins and Their Rôle in the Spread of Metastases. Ann. Surg., **112:** 138–149, 1940.
3. Coman, D. R.; DeLong, R. P.; and McCutcheon, Morton: Studies on the Mechanisms of Metastasis. The Distribution of Tumor in Various Organs in Relation to the Distribution of Arterial Emboli. Cancer Res., **11:** 648–651, 1951.
4. Geschickter, C. F., and Copeland, M. M.: Tumors of Bone. Ed. 3. Philadelphia, J. B. Lippincott Co., 1949.
5. Jaffe, H. L.: Tumors and Tumorous Conditions of the Bones and Joints, pp. 589–594. Philadelphia, Lea and Febiger, 1958.
6. Lichtenstein, Louis: Bone Tumors. Ed. 2. St. Louis, The C. V. Mosby Co., 1959.
7. Pathology. Edited by W. A. D. Anderson. Ed. 3. St. Louis, The C. V. Mosby Co., 1957.

Granulomatous Tenosynovitis Due to Beryllium
Histological and Spectrographic Analysis

A Case Report

BY E. D. VERE NICOLL, M.D., AND EUGENE A. FOSTER, M.D.,
CHARLOTTESVILLE, VIRGINIA

There have been numerous reports of granulomatous lesions of the skin and subcutaneous tissue that resulted from contamination of wounds by beryllium. The lesions occurred most frequently in workers engaged in the manufacture of fluorescent-light tubes and in individuals who were accidently cut by broken fluorescent bulbs. The only effective treatment for such beryllium granulomata has been excision of the affected tissue. Because extremely minute quantities of beryllium are capable of inciting the granulomatous reaction, even the small amount of beryllium that may be transferred to surrounding tissues by cutting into the lesion during excision may set the stage for recurrence. For this reason, wide excision of the skin lesions was advocated by Coakley and associates. In most cases, such wide local excision effects a permanent cure because the beryllium that has entered the subcutaneous tissues remains localized to the original area of contamination. In the case reported here local excision of a beryllium granuloma was ineffective in eradicating the disease because beryllium had entered and spread throughout a tendon sheath. In addition to the fact that it demonstrates an unusual type of spread of beryllium in the body, the case is of interest because it shows that beryllium may incite a severe granulomatous process in synovial tissue.

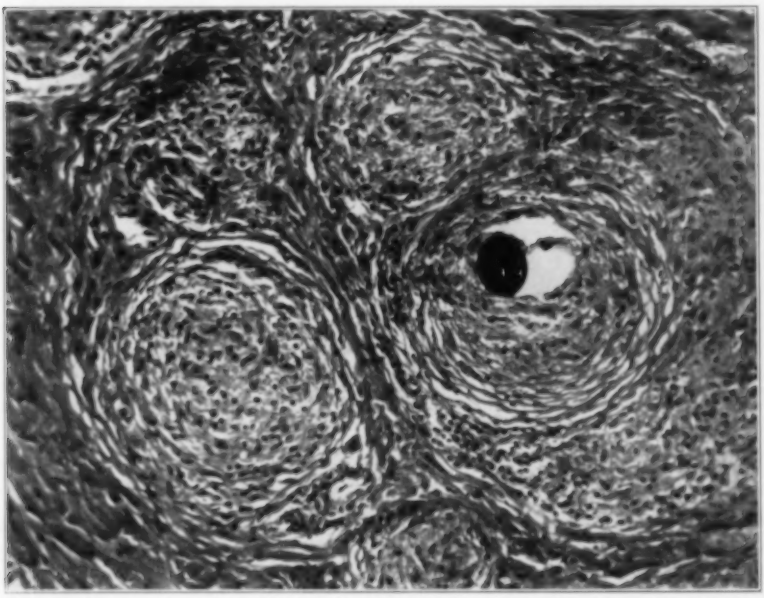


FIG. 1

Subcutaneous tissue from the first operation. Note the globule of mercury in the center of one of the granulomatous nodules (× 250).

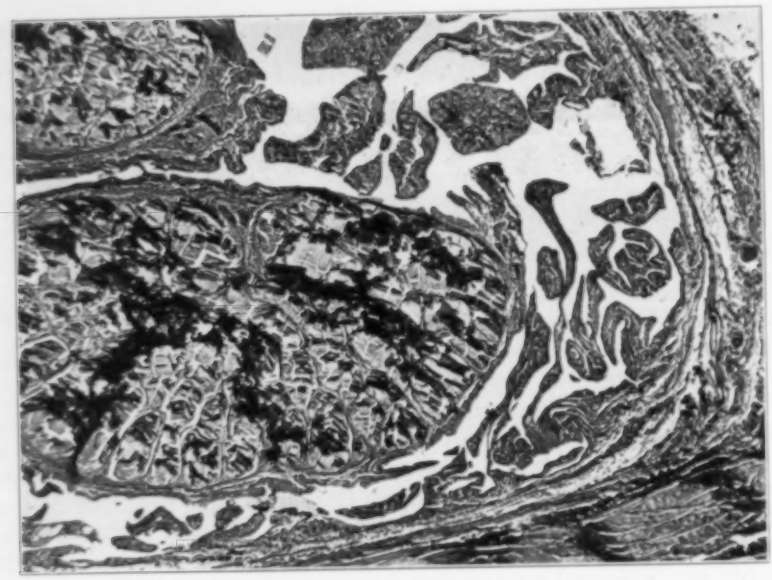


FIG. 2

Tendon sheath and contained tendons from the second operation. Note the involvement of both parietal and visceral synovial membrane (× 30).

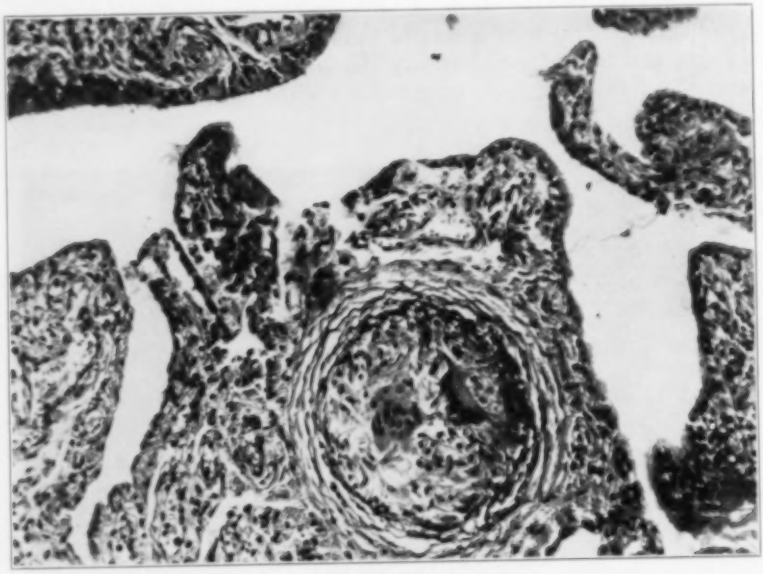


FIG. 3

Granulomatous tenosynovitis from the second operation. Note the sarcoid-like granuloma in one of the synovial folds (× 235).

The patient was first seen at the University of Virginia Hospital on August 1, 1954, when she was eight years old. Two years previously, while playing outdoors she had cut the palmar surface of the right ring finger over the middle phalanx on a broken fluorescent tube lying in the back yard of her father's store. About one year later a swelling was noticed on the finger, at the level of the middle phalanx.

Examination revealed a soft tumor attached to the skin, but not to the flexor tendons, beneath the palmar surface of the middle segment of the ring finger of the right hand. Roentgeno-

grams showed a few minute radiopaque bodies, which may have represented metallic fragments lying in the distal portion of the tumor, but there was no obvious involvement of the bone. Operation was performed on September 10, 1954, with the patient under general anesthesia. The tumor, which consisted of grayish, granulomatous material, was excised intact. The granuloma was adherent to the skin and flexor tendon sheath, but not to the underlying tendon. Great care was taken to leave the tendon sheath intact.

The specimen was an irregular fragment of somewhat granular gray-white fibrous tissue with no distinctive characteristics. Microscopically, it was seen to consist of dense fibrous tissue in which were embedded numerous closely packed sarcoid-like granulomata without caseation or calcification. In the centers of a few of the granulomata were dense, shiny black globules of metallic mercury which could be easily flattened out by pressure on the cover slip and which resumed their globular shape when pressure was released. No acid-fast bacilli or fungi were demonstrated; no doubly refractile crystals, Schaumann bodies, or asteroids were seen (Fig. 1).

The patient made a satisfactory recovery from this operation and was not seen again for five years, when she appeared with a painless, non-tender, fusiform, ill-defined swelling in the palm of the hand at the base of the right ring finger. The ring finger appeared to be normal to all intents and purposes. Range of movement was excellent and without pain.

A diagnosis of beryllium granuloma in the flexor tendon sheath was made and confirmed at operation in August 1959. The flexor tendon sheath was found to be ballooned out by the contained grayish material to such an extent that the proximal extremity of the flexor tendon sheath of the ring finger was shown very clearly.

Total removal of the flexor digitorum sublimis and profundus tendons together with their tendon sheath from the finger and palm was contemplated but it was found quite impossible to get around the granulomatous material in the finger, owing to its extension into the soft tissues. In the palm, on the contrary, it was found very easy to get around the granuloma because the process had not apparently spread outside the tendon sheath. Accordingly, an amputation of the ring finger and its metacarpal was accomplished without difficulty. The patient made a satisfactory recovery.

The specimen consisted of the entire right ring finger and the right fourth metacarpal bone. On the flexor surface, just proximal to the distal interphalangeal joint was a small atrophic scar. The proximal two centimeters of the tendon sheath was enlarged to a diameter of approximately 0.5 centimeter. The wall of the sheath was moderately thickened throughout its length. The synovial surfaces within the sheath did not present the normal smooth and glistening appearance; instead, they were shaggy and rough with innumerable fine papillary projections. The papillary proliferation involved the visceral synovial membrane covering the flexor tendons as well as the parietal synovial membrane (Fig. 2). The surfaces of the flexor tendons, where the tendons emerged from the proximal end of the sheath, appeared perfectly normal.

Microscopically, the papillary synovial processes were seen to consist of vascular fibrous cores which were covered by one or more layers of plump synovial cells. Moderate to intense infiltrations of lymphocytes and plasma cells were present in many regions. Small numbers of sarcoid-like granulomata were scattered throughout the thickened synovial membrane (Fig. 3). No acid-fast bacilli or fungi could be identified and no doubly refractile particles could be found. Neither Schaumann bodies nor asteroids were seen.

Spectrographic analysis of a sample of the thickened synovial membrane revealed the presence of beryllium in a trace amount (approximately one part per billion). A similar amount of silicon was also identified.

When the patient was last seen on February 10, 1960, six months after amputation, there was no sign of recurrence.

DISCUSSION

Although at least three foreign elements—beryllium, mercury, and silicon—were introduced into the tissue at the time of injury, we believe that the beryllium was responsible for the granulomatous reaction. Silicon, in the form of silica, is well known as an agent which can incite a granulomatous reaction in the soft tissues, as well as in the lungs. The absence of doubly refractile crystals in our patient, however, makes it unlikely that silica was the material that provoked the granulomatous response. We are not aware of any instances in which metallic mercury has been implicated as a cause of granuloma. In our case, the presence of mercury droplets in the centers of some of the granulomata might suggest that they had provoked the granulomatous reaction. We think it is much more likely

that beryllium was present along with the mercury and that the mercury only served as a visible evidence of the introduction of foreign material into the tissue.

The most logical explanation for the occurrence of the diffuse granulomatous synovitis of the tendon sheath is that beryllium entered the sheath near the point of the original injury and then spread through the synovial fluid to involve the entire structure. We cannot be certain whether the beryllium got into the tendon at the time of the original injury or during the operation for the removal of the soft-tissue lesion. Because particular care was taken not to enter the tendon sheath at the time of this first operation, we think that the contamination of the tendon sheath occurred at the time of the original injury. In any case, it is apparent that the granulomatous synovitis was a very slow progressive process which took over five years to reach the advanced stage at which it was found at the second operation.

It seems probable that the slow development of the tenosynovitis as compared with the subcutaneous granulomatous process was related to the comparatively low concentration of beryllium in the tendon sheath.

The fluorescent-light bulb involved in this case was probably an old one. We are informed that manufacturers of fluorescent tubes ceased using beryllium about 1949.

SUMMARY AND CONCLUSION

A case of granulomatous tenosynovitis of the flexor tendon sheath of a finger following a cut by a broken fluorescent bulb has been presented. The histological and spectrographic evidence indicate that beryllium was the causative agent. (The process took at least five, and probably seven, years before clinical manifestations appeared.) If contamination of a synovial surface by beryllium is known to have occurred, the possibility that severe synovitis may develop should be borne in mind when considering the patient's prognosis. Great care should be exercised to prevent contamination of synovial surfaces during the treatment of wounds believed to be soiled with beryllium.

REFERENCES

1. Ayers, W. W.; Ober, W. B.; and Hamilton, P. K.: Post-Traumatic Subcutaneous Granulomas Associated with a Crystalline Material. Am. J. Pathol., **27**: 303–315, 1951.
2. Coakley, W. S.; Shapiro, R. M.; and Robertson, G. W.: Granuloma of the Skin at Site of Injury by a Fluorescent Bulb. J. Am. Med. Assn., **139**: 1147–1148, 1949.
3. Grier, R. S.; Nash, Peter; and Freiman, D. G.: Skin Lesions in Persons Exposed to Beryllium Compounds. J. Indust. Hyg. and Toxicol., **30**: 228–237, 1948.
4. Hardy, H. L., and Stoeckle, J. D.: Beryllium Disease. J. Chronic Dis., **9**: 152–160, 1959.
5. Lederer, Henry, and Savage, John: Beryllium Granuloma of the Skin. British J. Indust. Med., **11**: 45–48, 1954.
6. Lehmann, H.: Granuloma of Boeck Disease Structure Caused by Beryllium Containing Foreign Bodies. Hautarzt, **7**: 173–176, 1956.

The Electrical Response of Human Skeletal Muscle to Passive Stretch*†

BY ROBERT O. BECKER, M.D., SYRACUSE, NEW YORK

From the Department of Orthopaedics, State University of New York, Upstate Medical Center, and Orthopaedic Section, Veterans Administration Hospital, Syracuse

In a recent series of articles Granit and associates [5,9,10] and Eccles and associates described two functional types of anterior horn cells in the cat. These they identified as tonic alpha and phasic alpha types; they considered them to be distinct from the gamma-circuit motoneurons. The activity of the tonic alpha cells is characterized by a sensitivity to passive stretch of the corresponding skeletal muscle with potentiation of the discharge on repeated stretching. The tonic motoneurons were considered to innervate tonic postural muscles, although to date no evidence for any such division of function in the skeletal muscles of man has been presented. The results reported [5,8,9,10] were based on decerebrate preparations. What the function of the tonic alpha cells and the postulated tonic postural muscles would be in the intact animal was not demonstrated.

The question of duality of the human neuromuscular system has been investigated and debated since Ranvier's observation in 1887 of the slower contraction rate and longer latent period of so-called red muscle as compared with so-called white muscle. It has been evident that the anatomical arrangement of the red muscles and their functional and electrical parameters favor a postural or tonic function, whereas the arrangement and parameters of the white muscles favor a voluntary or phasic function. Such a functional dichotomy, with two parallel anatomical systems, each containing neural and muscular units, was shown to be widespread among the invertebrates [14]. It was not until 1953, when Kuffler demonstrated the presence of slow fibers in the iliofibularis muscle of the frog, that the system was extended into the vertebrates. The work of Granit and associates and Eccles and associates, as just described, has recently revealed evidence for certain types of anterior horn cells in the cat that could form the neural portion of a tonic or postural neuromuscular system in that mammal. If evidence for a dual system in man could be obtained, many perplexing problems would be solved, both from the theoretical and the practical aspect. For example, to the clinician the existence of muscle tone is as evident as the existence of muscle spasm. Yet the single neuromuscular system does not contain sufficient functional parameters to explain the latter satisfactorily and, in fact, completely denies the existence of the former. In view of the widespread occurrence of dual neuromuscular systems in other forms of life, it would appear most logical that man would have, at least, the residuals of such an arrangement. In that case, abnormal functioning of any portion of the tonic system could produce the wide variety of clinical syndromes evidenced by postural abnormalities. Since the postural elements of such a system would most certainly have central (cranial) connections different from the voluntary system, they should be amenable to surgical manipulation without altering the function of the voluntary system. Furthermore,

* A preliminary report of this work was made at the Surgical Forum, Clinical Congress of the American College of Surgeons, Atlantic City, New Jersey, September 28, 1959.

† Supported by Veterans Administration Hospital, Syracuse, New York.

the specialized tonic muscle fibers may have different chemical mediators or have drug sensitivities different from the voluntary system and may therefore be medically influenced in a selective fashion.

Since the neuromuscular disorders remain a considerable problem to the clinician it would be of great interest to determine whether any evidence exists for such a duality of function in the human neuromuscular system. The motoneuron pool in the human being is not readily available for study, but the peripheral musculature is. An evaluation of the skeletal musculature under the conditions shown to produce activity of the tonic motoneurones may demonstrate activity of an analogous nature. Furthermore, the difference in such activity

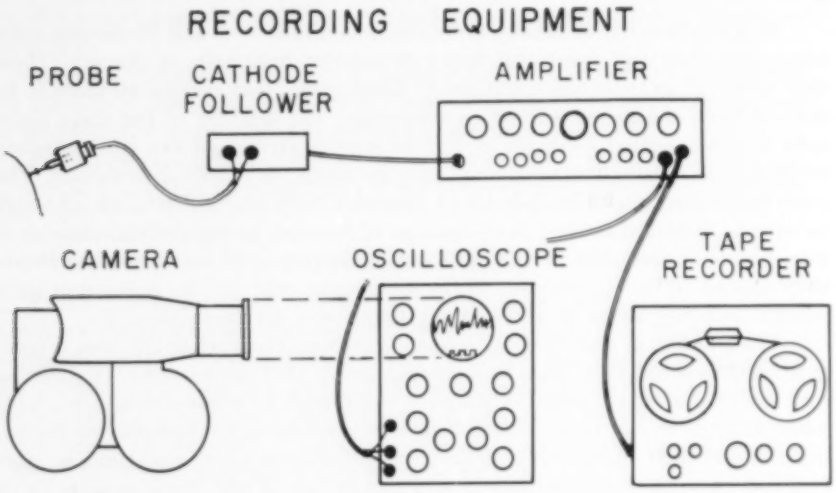


FIG. 1

Diagram of the experimental setup for obtaining the electromyograms used in the analysis. This setup is more elaborate than is necessary clinically but represents a method of considerable accuracy. As standardization of technique is becoming important in clinical electromyography, some consideration must be given to the accuracy of each method utilized.

between normal persons and those with muscular irritability due to disease would be interesting from the therapeutic and diagnostic viewpoints. (Of some importance in clinical experimentation is the fact that an intact preparation is used and decerebration or the like is not required to produce cooperation. Because of this the results in clinical experiments may not necessarily be similar to those obtained in animal experiments.)

METHODS

A modified coaxial needle electrode was used as the pickup device [1].

These electrodes have a small area of signal intercept (the spherical volume of muscle surrounding the tip of the electrode from which action potentials are picked up); they provide complete reproducibility of results from one case to the next; and they have excellent frequency characteristics. Additional instrumentation consisted of a direct-current preamplifier (Grass P6) and a dual-beam oscilloscope (Dumont 322A). Total noise level was measured at twelve microvolts under clinical conditions. The recordings were made with a Dumont 321A oscillographic camera on Kodak Linograph Pan film at a film transfer speed of 600 inches per minute. Simultaneous recordings were made on a frequency modulated tape recorder at a speed of 450 inches per minute. A second oscilloscope was

utilized for visual monitoring throughout the entire procedure. The experimental setup is schematically shown in Figure 1.

Wave analysis is a method of electronically breaking down a wave form into its component sine waves. It has been demonstrated that any wave form, regardless of shape, can be considered to be made up of pure sine waves of various frequencies. If the proper amounts of each sine wave are added simultaneously, the original wave form is reconstituted. A wave analysis spectrum, therefore, is a graph showing the relative amounts of electrical energy donated by each frequency to make up the original wave form. This method of analysis has proved to be a powerful tool in analyzing the function of various types of complex electronic equipment. As applied to electromyography: should two wave forms obtained under the same circumstances from the same site consistently demonstrate markedly different wave-analysis spectra then the electronic parameters of each wave form are also different and, more important, the mode of production of each wave form must be different, or different units must be utilized to produce the two different wave forms. In substance, even though two wave forms obtained on the electromyogram may look quite dissimilar they may still show the same wave-analysis spectrum and therefore be produced by similar units. On the other hand, if the spectra are dissimilar, then the two wave forms cannot be produced by similar units (unless one postulates that the functional parameters of the units have changed). Two points must be emphasized. First, even though the analysis breaks down a wave form into sine waves, this does not necessarily imply that the natural method of production of the wave was to combine these various sine waves. Second, the frequency spectrum applies to a single wave form; the frequency at which the wave appears (rate of action potential discharge) has no effect on the analysis and the analysis does not indicate the rate of discharge.

Wave analysis in the studies reported here was done from the magnetic tape recordings by isolating a 4.6-second section of the tape containing only the activity under investigation. This was set up as a playback loop running at the same speed as that used for recording. The output was bridged between a wave analyzer and one beam of the oscilloscope. The wave analyzer was of the continuously tunable filter type (Muirhead-Pamatrada) used in the maximum selectivity position (three decibels down at 0.6 per cent off tune). The graph points at intervals of twenty cycles per second were obtained by multiple recordings of the analyzer meter at each point throughout the range listed. In all instances, to obviate any effect of sixty-cycle interference, the position of sixty cycles per second was not recorded on the graph. Since the analyzer is used in the narrow-band position this in no way invalidates any other portion of the curve. The analyzer output was fed to the other beam of the oscilloscope, permitting a visual and photographic display of the amount of energy at any frequency range, compared with the wave forms presented on the other beam. The wave analysis setup is illustrated schematically in Figure 2.

The subjects were supine on a sponge-rubber mat, and sponge-rubber blocks one-inch thick were placed below the knees to effect complete relaxation. To obviate pain impulses from the skin about 0.1 cubic centimeter of 2 per cent procaine was injected intradermally at each insertion site. Multiple sites were evaluated within each muscle. Each site was subjected to the same sequence of events: rest, voluntary contraction, a series of ten passive stretches, and then terminal voluntary activity. Responses to needle insertion and movement were also evaluated. The passive stretch was effected by manually moving the appropriate joint through an arc of approximately 50 per cent of the normal range of motion. Each stretch cycle lasted about five seconds and there were no pauses

between the stretches. Muscles routinely evaluated were: the gastrocnemius, the soleus, the anterior tibial, and the long and lateral heads of the triceps humeri.

Subjects were chosen from the patient population of the orthopaedic and neurological wards of this general hospital. Normal volunteers were patients recovering from a variety of minor orthopaedic procedures done more than one month before. They were all completely ambulatory and exhibited no signs or symptoms of neuromuscular disease. In no case was an extremity evaluated on which an operation had been performed. Patients with neurological diseases included those with herniated disc, polymyositis, and what was considered to be benign epidemic myalgic encephalomyelopathy. The criteria used for the selection

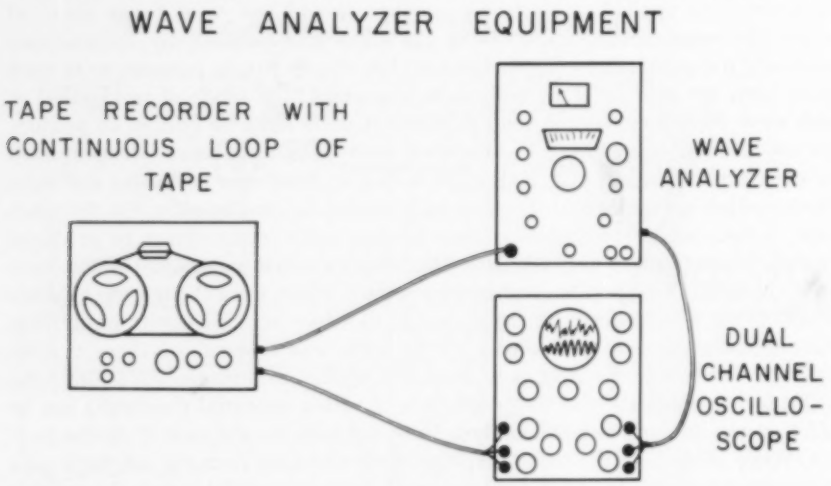


FIG. 2

Diagram of the experimental setup used for the wave-analysis procedure. The tape containing only the group of wave forms to be analyzed is made into a loop of specific length and played back repeatedly by the tape recorder. The output of the tape recorder is bridged between the wave analyzer and one beam of the oscilloscope. The individual sine wave sequences isolated by the wave analyzer pass to the output meter and to the other beam of the oscilloscope. The amplitude of each sine wave indicates the relative proportion of that specific frequency which goes to make up the original wave form.

of cases and the characteristics of the cases will be discussed in corresponding portions of the following section. (A total of thirty persons was evaluated by the methods described.)

RESULTS

In all eight normal volunteers electrical responses to passive stretching were noted in the long head of the triceps and in the soleus muscles. The anterior tibial muscles also showed similar activity, but it was of lower magnitude and not consistent. The gastrocnemius and the lateral head of the triceps were uniformly silent to stretch. In the soleus and long head of the triceps the activity appeared as a high-frequency discharge, predominantly positive and occurring as a burst generally 0.01 to 0.02 second in duration, just before maximum stretch was reached or just after the relaxation phase began. This relationship to the phase of the stretch cycle was constant in all cases. The amplitude of the activity was uniformly low during the first stretch (under 50 microvolts) and decreased in magnitude with each succeeding stretch until it was no longer visible after the third or fourth stretch. The low level of activity in these normal muscles necessi-

tated running the amplifiers at twice the usual gain. This produced a readable wave form without distortion but did increase the level of sixty cycles per second interference (Fig. 3, *b*, *c*, and *d*). The most common wave form encountered was an initial sharp positive deflection, followed by a slower return to the base line. This was most easily visualized on the first stretch where the magnitude enabled easy visualization (Fig. 3, *b*). As the magnitude diminished or the repetition rate increased or as both of these phenomena took place, the discharges appeared more random in nature although they usually retained their predominantly positive sign. One is led to believe, when watching these events, that the discharges are from the same source in all cases, and that the basic wave form is the one appear-

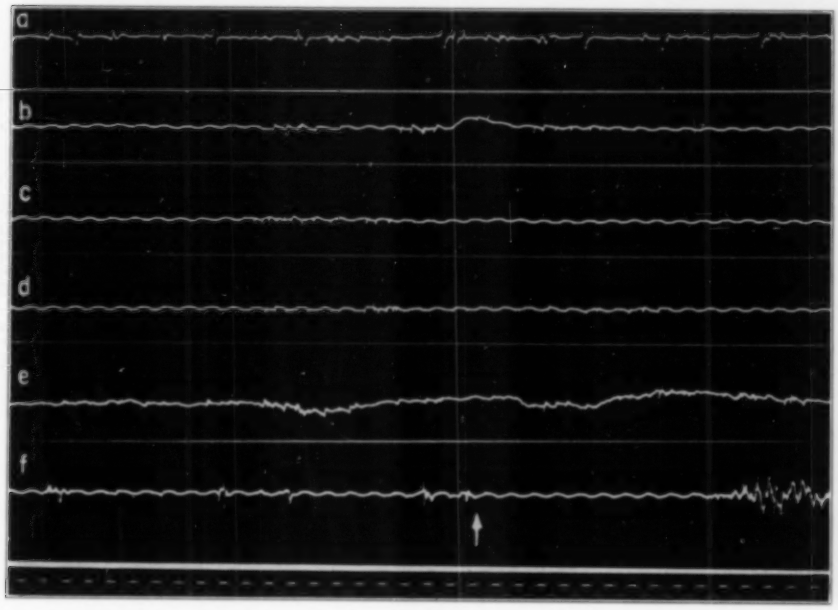


FIG. 3

Electromyograms from stretch-sensitive area of the soleus muscle of a normal subject. *a* indicates voluntary activity; *b*, response to first stretch; *c*, response to second stretch; *d*, response to third stretch; *e*, maximum response obtained from same area, first stretch of second-stretch cycle; and *f*, terminal voluntary activity. The arrow indicates cessation of the voluntary activity; the wave forms following the arrow are a spontaneous burst of high-frequency activity.

The voluntary activity is normal in pattern and amplitude. The stretch responses (*b*, *c*, and *d*) are typical positive waves of high-component frequencies, diminishing from the first stretch to the third. The stretch response in *e* is a more marked response and, although still mostly positive in sign, shows the result of interference between wave forms. In all cases the difference between the voluntary activity action potentials and the stretch response is apparent. (Calibration signal sixty cycles per second and fifty microvolts amplitude.)

ing on the first stretch. Visually, this activity is quite easy to distinguish from the activity associated with voluntary contraction and recorded from the same site (Fig. 3, *a*). It was noted that approximately one site in five sampled would show the stretch response in either muscle, the other sites being silent to stretch. However, a silent area was always silent to stretch regardless of the number of stretch cycles used, and an area demonstrating the stretch response continued to do so provided a few minutes rest was permitted between each of the stretch series. When the electrode was retracted approximately five millimeters from an area showing the stretch response, no activity was noted on passive stretch. If the probe was then replaced as accurately as possible in its previous position,

the same stretch responses were obtained. It therefore appeared that small discrete areas were responsible for the activity. In two of the normal subjects evaluated, areas within the soleus that produced the stretch response also showed bursts of similar high-frequency activity either during the initial portion of, or following the cessation of, the terminal voluntary contraction (Fig. 3, *f*). These patients volunteered the information that they felt a simultaneous, involuntary shift within the muscle. Occasionally, short bursts of high-frequency units could be produced by needle insertion or movement in the soleus muscle. These were inconsistent and lower in amplitude than those obtained in response to passive stretch and did not show potentiation with repeated needle movement.

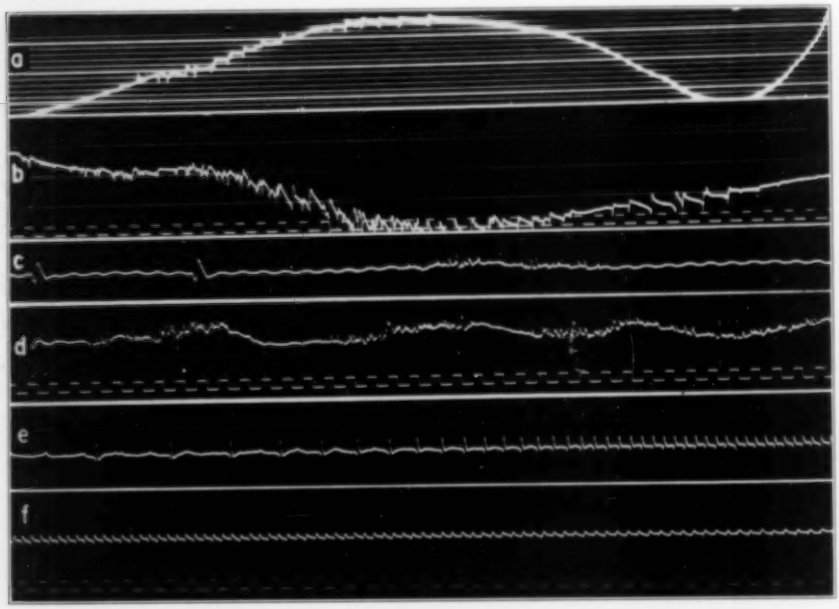


FIG. 4

Stretch responses of muscles in patients with herniation of an intervertebral disc and patients with polymyositis. *a* indicates response to first stretch (soleus) in a herniated-disc lesion (fifth lumbar-first sacral); *b*, response to third stretch, same patient and same site as *a; c*, response to first stretch (soleus) in polymyositis; *d*, response to tenth stretch, same patient and same site as *c;* and *e* and *f* indicate continuous record of response to first stretch of long head of triceps—polymyositis with atrophy of the triceps. The initial positive deflections in *f* do not register on the print. (Calibration signal sixty cycles per second and 100 microvolts amplitude.)

The wave forms in Fig. 4 should be compared with those in Fig. 3. Their similarity to the stretch responses in normal muscle is evident, a sharp initial positive phase followed by a slower negative phase. The initial amplitude is much greater than in the normal subject and the amplitude increases with repeated stretching (*a* and *b*). All of these wave forms are clearly different from those seen during voluntary activity.

Eleven patients with herniated discs in the lumbar region between the fourth lumbar and first sacral vertebrae were evaluated; the condition was proved at operation in eight patients and myelograms were positive in three. Patients with minimum clinical signs were deliberately chosen; none showed fibrillation or fasciculation potentials. (In my experience these signs are usually associated with severe nerve-root compression, in which case the clinical diagnosis is evident.) Electrical responses to stretch identical with those described in the normal subjects were noted in the soleus muscles. These bursts of electrical activity retained the same consistent relationship to the phase of the stretch cycle as was previously noted in the normal subjects. The amplitude, however, was much greater (over

100 microvolts) and the discharge increased with succeeding stretches sometimes associated with shifts of the base line (Fig. 4, *a* and *b*). The increase in the discharge consisted in increases in the amplitude of the discharges and in the frequency of individual pulses, as well as an increase in the duration of the total discharge. (In a few cases the terminal contraction was followed by a burst of similar high-frequency units.) This increased activity was uniformly present on the same side as the herniated disc, the contralateral extremity showing a normal reaction, that is, a decrease with each succeeding stretch. In those subjects in whom a herniated disc was present between the fourth and fifth lumbar vertebrae, the anterior tibial muscle on the affected side was usually slightly weaker to

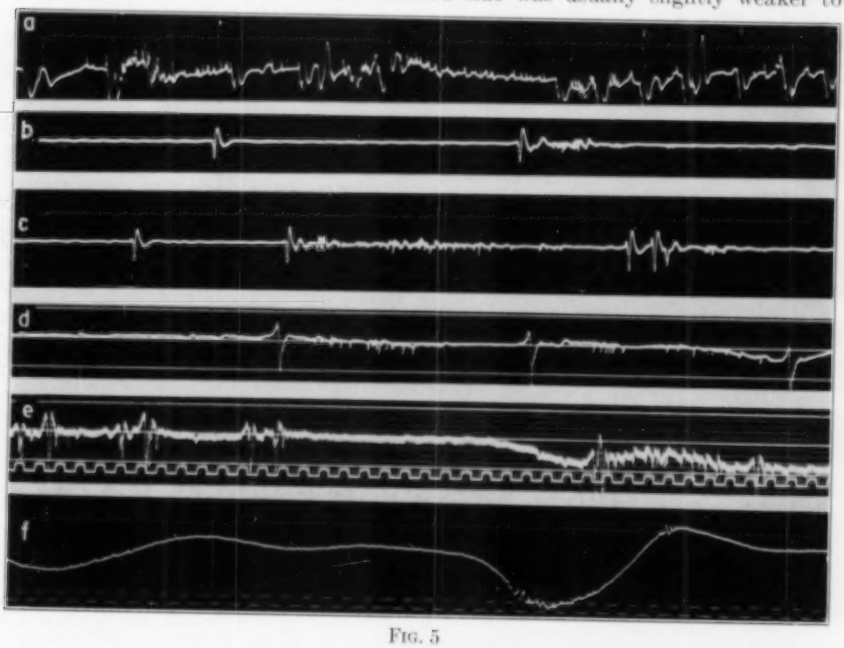


FIG. 5

Electromyograms in polymyositis. *a* indicates the high-frequency activity occurring initially during voluntary activity of the soleus: *b*, *c*, and *d* indicate the high-frequency activity following fasciculation impulses of the soleus; *e* indicates the burst of high-frequency activity following voluntary activity of the triceps (note also the polyphasic action potentials); and *f*, the high-frequency activity occurring during needle movement. (Calibration signal sixty cycles per second and 100 microvolts amplitude.)

All of these electromyograms show spontaneous activity similar to that found on stretching. In each case, however, there was a change in the tension-length relationship of the muscle—such as the beginning or ending of a contraction—that brought about the burst of high-frequency units.

clinical testing than that on the contralateral side. Nevertheless, the stretch responses of these two muscle groups were equal, of very low amplitude, and sparsely scattered throughout the muscle bulk. The gastrocnemii on both sides were silent to stretch procedures.

Eight cases considered to be polymyositis were evaluated. Clinically, these patients showed muscle weakness and atrophy about the shoulders and hips, as well as severe cramps in all extremities. They were evaluated jointly by the medical, neurological, and orthopaedic staffs and concurrence in the diagnosis was reached, using the criteria of Eaton. In seven of the cases biopsies of the involved muscles were compatible with the diagnosis. In all of the cases, diagnoses of anterior horn-cell disease or muscular dystrophy were considered less tenable than polymyositis. All patients in this group displayed high amplitude potentiating stretch responses

identical to those previously described in the subjects with herniated discs (Fig. 4, *c*, *d*, *e*, and *f*). These responses were particularly easy to produce, requiring only a minor amount of stretch, and they appeared much more uniformly distributed throughout the bulk of the muscle than in either the normal subjects or those with herniated discs. In the triceps muscle, atrophy was commonly encountered and decrease in the muscle bulk may be the explanation for the ease with which the stretch response was elicited in this muscle. The soleus muscle, however, was usually not involved in the atrophic process although it was also subject to severe cramps. Other observations included: the occurrence of after-discharges consisting in bursts of the same high-frequency units which followed fasciculation impulses (Fig. 5, *b*, *c*, and *d*), needle movement (Fig. 5, *f*), and voluntary contractions (Fig. 5, *e*). Responses to needle movement were frequent, but they did not show potentiation to repeated stimuli (movement). Occasionally, the terminal

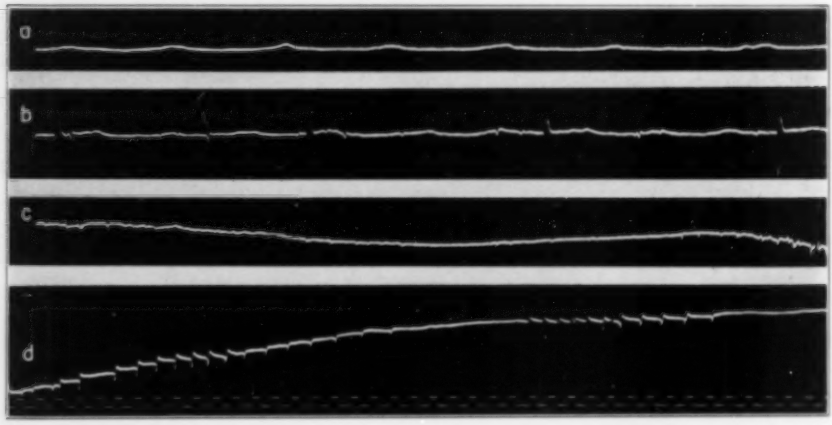


FIG. 6

Electromyograms from the soleus of a patient with benign epidemic encephalomyelopathy. *a* indicates resting, showing spontaneous slow wave potential; *b*, voluntary activity, showing scarcity of motor unit potentials, as well as the large amplitudes of these potentials and their clear wave forms; *c*, response to first stretch, showing small wave potentials; and *d*, response to third stretch, showing potentiation. (Calibration sixty cycles per second and 100 microvolts amplitude.)

The stretch responses are again of the same type as in the other illustrations. There is again an increase in the amplitude of each wave and in the total number of waves with repeated stretching.

voluntary activity showed high-frequency units in its initial portions (Fig. 5, *a*). In polymyositis, the biceps muscle usually was severely involved in the process and although electromyographic determinations were made on it in the same manner, stretch could not be readily accomplished by elbow motion. However, by manually grasping the biceps tendon and deflecting it sideways the muscle could be put under some stretch tension. Under these circumstances no electrical responses were noted to the cyclic stretching procedure. After-discharges were noted following voluntary contractions, but these were not high-frequency bursts.

Three cases studied were considered to be benign epidemic myalgic encephalomyelopathy on the basis of the clinical findings. The clinical characteristics of this condition are much less clearly defined than polymyositis and therefore the diagnosis is somewhat in doubt [12, 24]. These patients gave a history of sudden onset of the disease. Headache, nausea, vomiting, and pyrexia were followed by muscular weakness accompanied by severe peripheral muscular cramps. As the acute symptoms subsided, weakness and cramps remained in scattered muscle groups—generally in the muscles of the pelvic and pectoral girdles—and demon-

strable atrophy appeared. It was during this phase of atrophy that these patients were evaluated. No special treatment was subsequently rendered and all three patients made gradual but complete recoveries. In two, the triceps muscle was involved; it demonstrated high amplitude and potentiating stretch responses. In the third patient the calf muscles were involved and the soleus showed the same reaction (Fig. 6). In each patient the other muscles were evaluated; the results were identical to those recorded in the normal series.

Wave analysis was performed on recordings from selected subjects in each group. In each case voluntary activity and stretch responses taken from the same site within the muscle were evaluated. The voluntary activity spectrum was identical to that reported by other workers [11,21] (Fig. 7, **a**). The spectrum of the

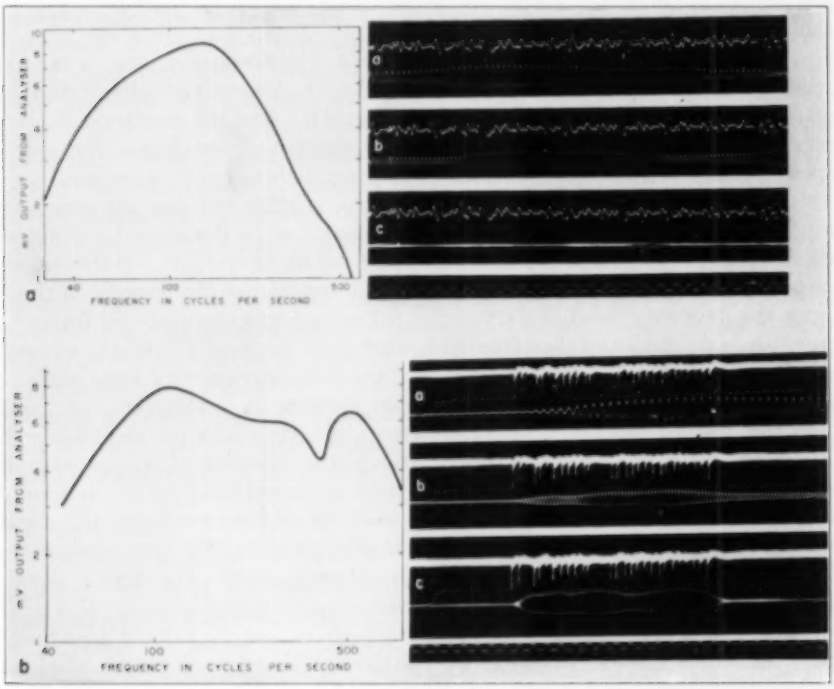


FIG. 7

a: A wave analysis of voluntary activity. At the left is the graph obtained from the output meter of the wave analyzer. The horizontal scale represents the frequency of the sine waves; the vertical, the amplitude at each frequency. The major contribution to the voluntary wave form is in the section labeled 100 to 200 cycles per second. At the right are three representative oscilloscope tracings for three different frequencies. In each case the upper line is the electromyographic wave-form group being analyzed and the lower tracing is the sine wave content at the single frequency listed: *a* = 150 cycles per second, *b* = 200 cycles per second, and *c* = 500 cycles per second. The very small contribution from the frequencies of 500 cycles per second is evident.

b: A wave analysis of a typical stretch response. The graph at the left demonstrates a rather marked peak in the section labeled 500 cycles per second with amplitudes here equaling those at 150 cycles per second. The oscilloscope presentations at the right are for the same frequencies as in Fig. 7, *a*, and the large amount of energy at 500 cycles per second in the wave form is clearly evident.

stretch response was in all cases markedly different from that of the voluntary contraction, showing a displacement toward the higher frequencies with a constant peak in the region of 500 to 600 cycles per second (Fig. 7, **b**). The same spectrum was obtained from all the stretch records analyzed regardless of differences in wave form. Even when the sharp positive wave forms were particularly

prominent (see results with normal muscles) the spectrum of the stretch response was not altered.

DISCUSSION

Electrical activity associated with passive stretch has been found in certain muscles of thirty subjects. This activity always maintained a definite relationship with the phase of the stretch cycle and was uniformly of a wave form visually and electronically distinguishable from the activity associated with voluntary contraction. In the normal subjects the activity decreased with succeeding stretch cycles, whereas in patients with disease characterized by hyperirritability of the skeletal muscles the activity increased with succeeding stretches. The soleus and long head of the triceps consistently demonstrated the activity, whereas the gastrocnemius was uniformly silent. The anterior tibial and lateral head of the triceps showed very sparse activity.

Similar wave forms have been encountered in denervated muscle or muscle rendered hyperirritable by peripheral nerve lesions [16] or polymyositis [19] and in so-called normal muscles of the anesthetized rabbit [20] and the muscles of rabbits on diets deficient in alpha-tocopherol [7]. In all reports the wave forms were noted spontaneously or on needle movement; passive stretch was not carried out.

It is felt that the activity reported herein is genuine and does not represent interference or artifacts arising within the apparatus. In the normal volunteers the increase in the gain produced an increased sixty-cycle artifact, but the stretch response wave forms were clearly evident on inspection of the records. In these cases the frequency band of sixty cycles per second was also excluded from the wave-analysis graph and therefore did not influence the results of this procedure. In all patients, both normal and diseased, the voluntary-activity wave analysis agreed closely with that obtained by other workers. It is therefore concluded that this method of dealing with interference of sixty cycles per second is well within the limits of standard accuracy. It is further concluded that pain stimuli were not connected with the phenomenon since the same technique was uniformly employed throughout the study; however, in all the subjects evaluated, the soleus muscle reacted to stretch with electrical activity, whereas the gastrocnemius—its immediate anatomical neighbor—was uniformly silent. The degree of discomfort would seem to have been nearly identical in both instances. However, the correlation between the presence of the activity and the acknowledged postural function of the soleus is evident [5]. The bursts of activity occurring in response to needle insertion and movement appear to be the same as those occurring during passive stretch. Potentiation was never noted in the needle movement series; however, it was definitely present in the stretch series. It is therefore concluded that the responses obtained during stretch are the results of the stretch stimuli and not the result of needle movement accompanying stretch. However, it cannot be said that the activities produced by stretch and needle movements are not produced by the same anatomical units. The same motor units may be stimulated by both needle insertion and stretch. If these fibers are analogous to the slow fibers of invertebrate muscles then they should be capable of local, non-propagating responses, and needle insertion or movement could produce this type of reaction. The important point, however, is that the stretch responses differ quantitatively from the responses to needle insertion. One explanation for this difference would be that stretch obviously involves the entire muscle as a functional unit and that the potentiation produced is the result of the activity of all portions of the tonic neuromuscular system, not just the local fibers.

The occurrence of the stretch response from restricted sites within the muscle bulk and the reproducibility of results (see section on normal muscles) indicate

that under the experimental conditions the tip of the probe remained relatively fixed within the same area for the entire test event sequence. This fact, in addition to the small area of signal pickup of the probe used, mediates against the activity recorded being distant units with wave-form distortion produced by travel through the muscle bulk. Under these circumstances the application of wave analysis to the two types of activity would seem to be valid.

The possibility that these responses result from activity of the intrafusal fibers within the muscle spindles cannot be ruled out. Boyd is of the opinion, based on histological evidence, that the small intrafusal fibers may be analogous to the slow tonic fibers of invertebrates. At present, however, definite evidence as to the abundance of the spindles within human postural muscles is lacking. They are known to be plentiful in the extra-ocular muscles and the intrinsic muscles of the hand, but can only be presumed to be more abundant in the postural muscles of the limbs than in the non-postural muscles in the same areas [2]. The results described in the present paper would indicate that if the responses were arising in the intrafusal fibers, then the spindles are much more numerous in the large postural muscles than they are thought to be. They would also be of greater importance than is generally thought. Although at this time the question must remain open until more definite histological evidence is forthcoming, it appears unlikely that the spindle fibers are the source of the activity recorded.

The constancy of the character of the discharge, the visual and electronic differences between it and the discharge accompanying voluntary contraction, the difference in potentiation between the normal and disease states, and the occurrence of the discharge primarily in postural muscles, all indicate that the activity recorded is genuine and that it represents a specific reaction of certain areas of the skeletal muscle to passive stretch. Whether these areas are composed of a different type of muscle fiber has not been determined. The electrical parameters of the discharge in the stretch response are sufficiently different from those of voluntary contraction to indicate, at the very least, a difference in the method of production.

It is not within the scope of this paper to attempt a complete review of the various aspects of the dual neuromuscular system. The interested reader is referred to the excellent monographs of Hoyle and, particularly, of Krüger. For clinical understanding, however, it may be said that this system provides for two separate complete neuromuscular systems. One system, functioning automatically through specialized neural connections, acts upon specific muscle fibers by means of multiple end plates. These specific muscle fibers are capable of slow, sustained contractions of low magnitude with great resistance to fatigue; these fibers generate only local, non-propagating, electrical impulses. The other system, operating through neural connections of a voluntary or semi-automatic nature, acts upon muscle fibers by means of single end plates. These muscle fibers tire easily but generate propagated impulses throughout their length and contract very quickly and with great force. The entire system has been fully investigated and all components found and studied in the invertebrates. In the frog the slow muscle fibers have been located, whereas in the cat only the specialized anterior horn cells have been thus far described. In the peripheral musculature, however, fibers with multiple end plates have been described histologically in the monkey by Feindel and associates and electrically in the cat by Hunt and Kuffler. Previous attempts to obtain electromyographic evidence in the human being of specialized postural fibers have been unsuccessful [13,22]. The present paper is the first attempt to obtain such information based on the known parameters of the specialized anterior horn cells, as described by Granit and associates

and Eccles and associates, and the known parameters of the tonic muscle fibers, as described by Hoyle. The criteria utilized were:

1. The electrical activity of the tonic fibers should be distinguishable from that obtained during voluntary activity, both visually and electronically;

2. The electrical activity should be related consistently to the phases of the stretch of a muscle containing such fibers;

3. Potentiation of the activity should occur with repeated stretching;

4. Such activity should be present in greater abundance in muscles with a postural function (although this does not obviate the possibility of such fibers being present in other muscles, for example, in those requiring very fine, controlled motions).

Each of these criteria appear to have been fulfilled in the present study. The clinical importance of the exaggerated tonic fiber activity (on electromyography) in certain diseases is obviously an immediate diagnostic aid but may also become of even greater importance therapeutically as more information is obtained relative to the entire human neuromuscular system.

SUMMARY

A refined technique of electromyography and electronic analysis was utilized to determine the responses of several muscle groups to passive stretch. Distinctive responses were obtained in the soleus and long head of the triceps humeri. In the normal person these had a definite relationship with the phase of the stretch cycle, were about fifty microvolts in amplitude initially, and diminished on repeated stretching. In patients with disease characterized by hyperirritability of the skeletal musculature, the same responses were obtained in the same muscles. However, in these subjects the initial amplitude averaged 100 microvolts and repeated stretching produced a marked increase in amplitude and duration of the discharge. In all subjects the responses were confined to multiple discrete areas within the muscle bulk. The gastrocnemius and the lateral head of the triceps were silent to repeated stretching. A few scattered non-potentiating discharges were found in the anterior tibial muscle of some of the diseased patients.

The possible sources of error in the investigation are considered and discussed in relation to the findings. These results correlated well with tentative criteria for the presence of tonic muscle fibers, based on recent indentification of tonic anterior horn cells in the cat. Further investigation in clinical syndromes seems warranted. The activity in the patients with neuromuscular disorders appeared to be analogous to the activity of the tonic motoneurons in decerebrate preparations. The experimental results indicate some duality of function in the skeletal musculature of the human being.

REFERENCES

1. Becker, R. O., and Chamberlain, J. T.: A Modified Coaxial Electrode for Electromyography. Arch. Phys. Med. and Rehabil., **41**: 149–151, 1960.
2. Bowden, R. E. M.: The Innervation of Skeletal Muscle. British Med. J., **1**: 671–674, 1960.
3. Boyd, I. A.: The Innervation of Mammalian Muscle Spindles. J. Physiol., **140**: 14P–15P, 1958.
4. Eaton, L. M.: The Perspective of Neurology in Regard to Polymyositis. A Study of Forty-one Cases. Neurology, **4**: 245–263, 1954.
5. Eccles, J. C.; Eccles, R. M.; and Lundberg, A.: Duration of After-hyperpolarization of Motoneurones supplying Fast and Slow Muscles. Nature, **179**: 866–868, 1957.
6. Feindel, William; Hinshaw, J. R.; and Weddell, G.: The Pattern of Motor Innervation in Mammalian Striated Muscle. J. Anat., **86**: 35–48, 1952.
7. Fudema, J. J.; Oester, Y. T.; Fizzell, J. A.; and Gatz, A. J.: Electrical Activity of Striated Muscle in Experimental Vitamin E Deficiency. Am. J. Physiol., **198**: 123–127, 1960.
8. Granit, Ragnar: Neuromuscular Interaction in Postural Tone of the Cat's Isometric Soleus Muscle. J. Physiol., **143**: 387–402, 1958.
9. Granit, Ragnar; Henatsch, H. D.; and Steg, Göran: Tonic and Phasic Ventral Horn Cells Differentiated by Post-Tetanic Potentiation in Cat Extensors. Acta Physiol. Scandinavica, **37**: 114–126, 1956.

10. Granit, Ragnar; Phillips, C. G.; Skoglund, Sten; and Steg, Göran: Differentiation of Tonic from Phasic Alpha Ventral Horn Cells by Stretch, Pinna and Crossed Extensor Reflexes. J. Neurophysiol., **20**: 470–481, 1957.
11. Hayes, K.: Wave Analyses of Tissue Noise and Muscle Action Potentials. Air Crew Equipment Laboratory Publication 404. Philadelphia, Naval Air Material Center, 1959.
12. Hill, R. C. J.; Cheetham, R. W. S.; and Wallace, H. L.: Epidemic Myalgic Encephalomyelopathy. The Durban Outbreak. Lancet, **1**: 689–693, 1959.
13. Hoefer, P. F. A.: Innervation and "Tonus" of Striated Muscle in Man. Arch. Neurol. and Psychiat., **46**: 947–972, 1941.
14. Hoyle, Graham: Comparative Physiology of the Nervous Control of Muscular Contraction. London, Cambridge Univ. Press, 1957.
15. Hunt, C. C., and Kuffler, S. W.: Motor Innervation of Skeletal Muscle: Multiple Innervation of Individual Muscle Fibres and Motor Unit Function. J. Physiol., **126**: 293–303, 1954.
16. Jasper, Herbert, and Ballem, Gwen: Unipolar Electromyograms of Normal and Denervated Human Muscle. J. Neurophysiol., **12**: 231–244, 1949.
17. Krüger, Paul: Tetanus und Tonus der Quergestreiften Skelettmuskeln der Wirbeltiere und des Menschen. Leipzig, Geest und Portig, 1952.
18. Kuffler, S. W.: The two Skeletal Nerve-Muscle Systems in Frog. Arch. Exper. Pathol. u. Pharmakol., **220**: 116–135, 1953.
19. Lambert, E. H.; Sayre, G. P.; and Eaton, L. M.: The Electrical Activity of Muscle in Polymyositis. Trans. Am. Neurol. Assn., **79**: 64–69, 1954.
20. Landau, W. M.: Synchronization of Potentials and Response to Direct Current Stimulation in Denervated Mammalian Muscle. Electroenceph. and Clin. Neurophysiol., **3**: 169–182, 1951.
21. Nightengale, A.: The Analysis of Muscle Potentials by Means of a Muirhead-Pamatrada Wave Analyzer. Technique, **11**: 27, 1959.
22. Ralston, H. J., and Libet, B.: The Question of Tonus in Skeletal Muscle. Am. J. Phys. Med., **32**: 85–92, 1953.
23. Ranvier, L.: Des muscles rouges et des muscles blancs chez les rongeurs. Compt. Rend. Acad. des Sciences, **1**: 79–80, 1887.
24. Richardson, A. T.: Some Aspects of the Royal Free Hospital Epidemic. Ann. Phys. Med., **3**: 81–89, 1956.

The Exchange Fellows from Great Britain made during the Spring a tour of various orthopaedic centers in the United States. This year San Antonio was one of the centers visited; thus early one morning before a clinical tour this photograph of the Fellows was made in front of the Alamo. The Fellows are (left to right): John W. Dickson, England; William G. Doig, Australia; James H. Scott, Scotland; Anthony H. C. Ratliff, England; and H. C. Robins, England.

Proceedings

THE VIRGINIA STATE ORTHOPAEDIC SOCIETY

The Annual Spring Scientific Meeting of the Virginia State Orthopaedic Society was held in Richmond, Virginia, on April 8 and 9, 1960. The officers of the Society present at the meeting were: Dr. William M. Deyerle, *President;* Dr. Earnest B. Carpenter, *Secretary-Treasurer;* and the Members of the *Program Committee* — Dr. Virgil R. May, Jr., *Chairman*, Dr. Beverley B. Clary, and Dr. M. Josiah Hoover. Dr. Edward L. Compere, guest lecturer, spoke on "Orthopaedic Errors and Safeguards".

The following papers were presented:

Operative Treatment of Knee Ligament Injuries. Dr. E. W. Hakala [1] and Dr. William M. Deyerle presented a paper based on Dr. Hakala's experience with some fifty cases seen in the army and thirteen seen in private practice. Emphasis was placed on the following points: (1) Careful evaluation of the knee with regard to relaxation of ligaments (lateral and cruciate). This examination can be done with the knee extended and flexed and, if necessary, with anesthesia; (2) The extravasation of swelling below the knee, which is indicative of rupture of the capsule; (3) Comparative roentgenograms made with the patient's knees held together; (4) Careful surgical technique with wide exposure, dissecting back the fascia to visualize the underlying tissues; (5) Meticulous repair of both layers of the collateral as well as the cruciate ligament; and (6) Protected, graduated activity of the knee to build up quadriceps power.

Follow-up of nine of the thirteen private patients showed excellent stability of the knee with minimum loss of flexion. Avulsion of ligaments of the knee, if properly diagnosed, will show better results when treated surgically than when treated by quadriceps exercises only.

Plication Repair of Medial Collateral Ligaments. Dr. R. D. Butterworth [2] discussed the relaxation of the medial collateral ligament in association with cartilage injuries. The author advocated plication of the capsular incision as tightly as possible whenever there is evidence of relaxation of the collateral ligaments. This procedure, combined with vigorous quadriceps exercises, will result in a satisfactory knee in most instances. Repair of the cruciate ligament is often not necessary.

Glomus Tumors of the Extremities. Dr. William Daner [3] reviewed the literature concerning this entity and presented a typical case.

The paper precipitated a lively discussion at which it was said that the diagnosis of glomus tumor was not always made by the pathologist even when it was, in fact, present clinically. Pathological diagnosis will vary considerably depending on whether the angiomatous element or the neurofibromatous element is predominant.

Transient Peroneal Palsy. Dr. Herman Nachman [4] described several interesting cases of peroneal palsy, which appeared after mild disease and were suggestive of true peroneal neuritis. In each instance the palsy was transient and cleared up after six to eight weeks. The value of electromyography in the diagnosis of the disease was emphasized.

Resistant Rickets. Dr. Robert Bowen [5], Dr. Herman Nachman, Dr. St. George Tucker, and Dr. Beverley Clary presented a paper in which Dr. Bowen reviewed the literature concerning vitamin D-resistant rickets and discussed the pathological physiology involved in the disease. In patients with this disease the blood chemistry as well as the urinary output of calcium must be carefully followed to determine the dosage of vitamin D required for treatment. The need for massive and prolonged doses of vitamin D was emphasized, and the metabolic defect that makes this necessary was discussed and illustrated.

Orthopaedic Errors and Safeguards. Dr. Edward L. Compere [6], the Guest Lecturer, emphasized the need for considering the patient as a whole, and said that reliance on single laboratory procedures or tests must be avoided.

1. 2222 Monument Avenue, Richmond 20, Virginia
2. 501 East Franklin Street, Richmond 19, Virginia
3. 501 East Franklin Street, Richmond 19, Virginia
4. 1006 West Franklin Street, Richmond 20, Virginia
5. Medical College of Virginia, Hospital Division, Richmond 19, Virginia
6. 720 North Michigan Avenue, Chicago 11, Illinois

In reference to amputation after trauma the author emphasized the need for conservative treatment. Many apparently useless limbs, if given proper, immediate care and treatment by reconstructive surgery with rehabilitation, can be preserved and thus perform functions greatly superior to any prosthesis. On the other hand, if after a trial attempt to save an extremity it becomes apparent that treatment will have to be prolonged for one to two years and that amputation will ultimately be required, the best judgment would dictate amputation. Certainly, amputation is preferred to multiple surgical procedures, performed over many years, since these would eventually result in failure.

In the treatment of bone tumors, it is essential to have adequate material for biopsy for careful study to determine the proper treatment. Inadequate biopsies or needle biopsies have been the cause for much confusion and improper treatment.

Good compressive dressings before and after surgery are essential in all pathological conditions of the extremities. The proper use of compressive dressings will prevent many of the complications resulting from boggy, edematous tissues in which resistance is low and in which fibrosis and limitation of motion tend to develop.

The incision should be one that is least likely to cause deforming scars. Cosmesis should be secondary to exposure, but very frequently adequate exposure can be obtained with due allowance for incisions that do not stretch and widen after healing. In general, attempts should be made to cut in line with flexion and extension creases and to avoid long incisions in the regions of joints. Whenever possible, incisions should be parallel with the elastic fibers of the skin. When making an incision, the surgeon should also bear in mind the need for protection of the growth lines. In operations on children, indiscriminant surgery in the region of the growth line has frequently produced permanent growth disturbances.

Conservative Treatment of Tibial Shaft Fractures. Dr. James T. Tucker [7] and Dr. Frank Watkins studied 111 consecutive fractures of the tibial shaft—forty-three compound and sixty-eight simple. Infection was present in eight of the compound fractures (18.6 per cent of the compound fractures or 7.2 per cent of the total fractures). In fifty-eight patients in whom treatment was completed the average time until full weight-bearing was 26.5 weeks; in the eighteen compound fractures it was 30.3 weeks and in forty simple fractures it was 24.8 weeks. There were five (8.6 per cent) complications: two non-unions, which healed after bone-grafting; one infected non-union, which is now healing after resection of the bone and insertion of a Lottes nail; and two infections, which responded to conservative treatment and skin-grafting.

Conservative treatment of fractures of the tibial shaft is highly satisfactory and in many ways superior to current methods of internal fixation.

Shoulder Fusions. Dr. Virgil R. May, Jr.,[8] said that there were three indications for shoulder fusion: poliomyelitis, benign bone cysts, and extensive injuries to the brachial plexus. The author described the joints participating in abduction and extension of the shoulder, the anatomy of the shoulder girdle, and his technique of shoulder fusion. Fixation of the glenohumeral articulation is achieved by a wooden screw; later, a plaster shoulder spica can be applied without concern with position at the fusion site.

Preoperative and postoperative roentgenograms and photographs of fourteen patients were shown. The longest follow-up in this group of patients was seventeen years.

Complicated Fractures about the Elbow. Dr. William M. Deyerle [9] and Dr. Don Howell discussed eleven cases of severe fracture around the elbow. Eight patients had severely compounded and comminuted fractures; in four, amputation was recommended as the primary procedure. The longest follow-up was nineteen years; this patient returned to military duty after his fracture had been repaired and, at present, is getting along very well.

In compound fractures about the elbow, a tourniquet should be applied and careful and thorough débridement carried out. After the tourniquet is released the vitality of the tissues should be evaluated. Soft tissue should be covered in all areas, using a relaxant incision and skin graft, if possible. Drains should be used generously.

Absolute internal fixation allows maximum opportunity for revascularization of the soft tissues, increases resistance to infection, and offers maximum opportunity of revascularization and union at the fracture sites. It also makes possible early motion of the affected joints. In simple fractures that cannot be maintained in good position with closed reduction and cast, open reduction is preferable to traction. In the elbow region adequate immobilization and alignment of the

7. 116 East Franklin Street, Richmond 19, Virginia
8. 2222 Monument Avenue, Richmond 20, Virginia
9. 2222 Monument Avenue, Richmond 20, Virginia

fracture fragments tend to prevent ischemic contractures distal to the fracture site.

If the surgeon will follow the principles just delineated, even the patient with the most severe fracture can obtain an excellent, functional extremity which, in most instances, will be greatly superior to any prosthesis.

End-Result Study of Operation for Fusion of the Hip. Dr. Earnest B. Carpenter [10] and Dr. James Banks reported on nineteen hip fusions performed at Maguire Veterans Hospital. (It was interesting that at this institution more hip fusions had been done than arthroplasties, including prostheses.) Various types of procedures were used and the authors felt that a solid hip fusion was in most instances preferable to the arthroplastic or prosthetic procedures. Of the nineteen hips operated on, there was failure of fusion in only two. In the discussion which followed there was an interesting debate concerning the optimum position of fusion. It was also brought out that subtrochanteric osteotomy certainly had a salutary effect on the speed of fusion.

Recurrent Dislocations of the Shoulder. Dr. Beverley Clary [11] presented his experience with twenty-five cases of recurrent dislocation of the shoulder. He felt that the Bankart procedure was the best method to prevent recurrences. However, when there was a large defect in the glenoid rim he advocated a bone graft, which he preferred to take from the humerus. He emphasized the need for transplanting the subscapularis slightly laterally to limit external rotation.

Repair of Bone Defect in Recurrent Dislocation of the Shoulder. Dr. William M. Deyerle [9] said that the inherent advantage of the Bankart procedure over the Putti-Platt lies in the fact that the weak spot at the edge of the glenoid is directly reinforced in the Bankart procedure, but is merely tightened up and stretched in the Putti-Platt procedure. The author described a method of using two three-quarter-inch cruciate-head screws to act as an anchor for two silk sutures when fastening the capsule into the defect. This method had the advantage of extreme ease of insertion and the heads of the screws tend to form a buttress, very much as a bone graft does, against which the labrum, if it is intact, can be placed. If the labrum is not intact it is usually excised. The same technique can be applied by using a bone graft and drilling holes through the graft so that the portion which protrudes will have two spots through which to suture the capsule of the joint. If one wishes to obtain full external rotation the subscapularis is not transplanted laterally; if one wishes to limit this motion slightly with more assurance of success it may be transplanted laterally. It is routinely transplanted slightly inferiorly with the lower edge of the subscapularis sutured underneath the capsule.

The paper was based on experience with sixteen patients. There was recurrence in only one and that was in a shoulder that should have had some buttressing to protect the large defect in the labrum; instead, the regular Bankart procedure was performed. It was this incident that convinced the author of the need for buttressing the defect—where there is a very large defect—with some material, either screws or bone graft.

Absolute Peripheral Fixation for Fractures of the Hip. Dr. William M. Deyerle [9] presented a movie showing multiple pin fixation in fractures of the neck of the femur. A plate attached to the side of the femur serves the dual purpose of a guide for parallel placement of the pins and for distributing the stress of the pins through the lateral cortex of the femur so that there is no loosening of the pins laterally. The pins are threaded in the head only and maintain an excellent grip. Impaction of the fracture is further accomplished by impacting the plate and tightening the screws with a lag screw effect. This gives sufficient fixation to allow weight-bearing three to five days after operation. (Ambulation stimulates new bone; lack of motion prevents absorption at the fracture site and there is no shortening of the neck.)

The film also showed postoperative pictures of various patients walking during different stages of healing, which is greatly accelerated by walking. There were twenty-seven patients with fracture of the femoral neck who were followed from one to three years. There was no nonunion and only one case of avascular necrosis. The method shown was used in intertrochanteric fractures. The neck fractures require five pins, whereas the intertrochanteric fractures require a minimum of seven pins. The total area of the neck which is taken up with five pins is slightly less than 5 per cent. The area taken up with the seven pins is slightly less than seven per cent. The author condemned the use of prostheses as a primary treatment of hip fractures.

Hip Prosthesis with Long Term Follow-up. Dr. Virgil R. May, Jr.,[8] showed films of three patients. One patient had had bilateral Naden-Reith hip prostheses inserted eight years

10. 116 East Franklin Street, Richmond 19, Virginia
11. 116 East Franklin Street, Richmond 19, Virginia

before. He was shown walking up steps and performing various maneuvers to demonstrate the range of motion of both hips. The range of motion in flexion and extension was good but there was some limitation of internal and external rotation. Current roentgenograms revealed a considerable amount of settling of the prostheses on the neck of the femora. There was no increase in calcification about the hip joint itself, nor was there any increase in arthritic changes in the acetabulum.

Another patient had had an Eicher prosthesis inserted in the right hip seven years before for painful arthritis. He also had an amputation of the left limb at the mid-thigh and used crutches for this limb. The right hip was painless and motion was good.

A white woman, seventy-eight years old, had had a Fred Thompson prosthesis inserted in the right hip three years before, following a fresh fracture. She could walk well, climb steps, sit well, and she had good range of motion of the hip. There was no calcification about the capsule of the hip joint and the right hip was painless.

CORRECTIONS

In the June 1960 issue of *The Journal* in the article Stabilization of the Cervical Spine by Anterior Fusion by R. W. Bailey and C. E. Badgley, the cut containing Figures 6-C and 6-D on page 575 was printed upside down. Thus when the cut is put right side up what is now Fig. 6-C will be Fig. 6-D and Fig. 6-D will be Fig. 6-C.

In the July issue of *The Journal* in the article Experimental Immobilization and Remobilization of Rat Knee Joints by E. Burke Evans, G. W. N. Eggers, James K. Butler, and Johanna Blumel, the legend for Figure 14, page 740, states that the period of immobilization was eleven days. This is not correct. The period of immobilization was 110 days.

News Notes

The **Philadelphia Regional Committee of Trauma of the American College of Surgeons** announces a course in Fractures and Other Trauma to be given March 2, 3, and 4, 1961, by Sir Reginald Watson-Jones, London. Also participating are Dr. John Royal Moore, Philadelphia, and Dr. Preston Wade, New York City. Further information may be had by writing to Dr. Lewis Manges, 2001 Delancey Place, Philadelphia 3, Pennsylvania.

A postgraduate course in cerebral palsy is open to participants of the Eighth World Congress, Foreign Students in the United States, and to a limited number of rehabilitation workers. It will be given during the three weeks following the Eighth Congress of the International Society of Orthopaedics and Traumatology. For further information, write: Dr. Isabel P. Robinault, Institute for the Crippled and Disabled, 400 First Avenue, New York 10, N. Y.

An **International Course of Traumatology and Orthopedy** will be held in Mexico City from August 25 to September 3, 1960. The course is sponsored by the National University of Mexico, the Primavera Clinic "Dr. Velasco Zimbrón", and the Mexican Institute of Social Security and is to be held in conjunction with the French-Mexican Week of Orthopedy. The following will participate: Professor Merle d'Aubigné, Professor Robert Judet, Professor Jean Cauchoix, Professor Pierre Lance, and Professor Paul Louis Chigot. The Primavera Clinic has invited Professor O. Scaglietti to participate and the Mexican Institute of Social Security has invited Professor José Luis Bado to take part.

The **American Association for Automotive Medicine** will hold its Annual Meeting in Dearborn, Michigan, September 19 and 20, 1960, under the auspices of the Ford Motor Company. Information and applications may be obtained from Dr. Harold A. Fenner, Jr., M.D., 115 West Sanger, Hobbs, New Mexico.

For several years scientists interested in basic problems of congenital malformations have held informal conferences in which questions of common interest were discussed. Anatomists, biochemists, embryologists, geneticists, obstetricians, pathologists, pediatricians, plastic surgeons, and others attended these conferences which were in part supported by the Association for the Aid of Crippled Children, New York, N. Y., and the Human Embryology and Development Study Section of the National Institutes of Health. With the increased interest in recent years in this area, it was felt that there was a need for a Society to hold regular meetings in which investigations concerned with etiology and morphogenesis of congenital malformations could be presented and discussed. Following the fourth teratology conference, which was held at the Memorial Sloan-Kettering Cancer Center in New York City and attended by seventy-six scientists from Canada, England, France, Germany, and the United States, **The Teratology Society** was formed for the purposes just outlined. The following officers were elected: *President:* Josef Warkany, M.D., Cincinnati, Ohio; *President-Elect:* James G. Wilson, Ph.D., Gainesville, Florida; *Secretary-Treasurer:* Marjorie M. Nelson, Ph.D., San Francisco, California; *Recorder:* Sidney Q. Cohlan, M.D., New York, N. Y.; *Council:* F. Clarke Fraser, Ph.D., M.D., Montreal, Canada; David L. Gunberg, Ph.D., Portland, Oregon; and M. Lois Murphy, M.D., New York, N. Y. The National Foundation assisted in the formation of the Society with advice and financial aid. Inquiries about The Teratology Society should be directed to Dr. Marjorie M. Nelson, Department of Anatomy, School of Medicine, University of California, San Francisco 22, California.

The **Exchange Fellowship Committee** of **The American Orthopaedic Association** is now inviting applications from American orthopaedic surgeons who are interested in the tour to Great Britain in the Spring of 1961. The requirements are: The applicant must be under forty years of age as of December 1, 1960; he must have completed Part 2 of the American Board of Orthopaedic Surgery examinations; and he must be a citizen of the United States. Requests for application blanks should be made to the Chairman of the Exchange Fellowship Committee, Dr. J. Neill Garber, 806 Hume Mansur Building, Indianapolis, Indiana.

The Part II examination for Certification by the **American Board of Orthopaedic Surgery** will be held January 4 through 6, 1961, at the Americana Hotel, Bal Harbour, Miami Beach, Florida. Sam W. Banks, *Secretary*, 116 South Michigan Avenue, Chicago 3, Illinois.

Addresses of Contributors

SEPTEMBER 1960

Alexander P. Aitken, M.D., 1180 Beacon Street, Brookline 46, Massachusetts

Robert O. Becker, M.D., Veterans Administration Hospital, Irving Avenue and University Place, Syracuse 10, New York

William H. Bickel, M.D., Mayo Clinic, Rochester, Minnesota

Captain Charles A. Borgia, M.C., U.S.A.F., 3535 U.S.A.F. Hospital, Mather A.F.B., California

S. S. Coleman, M.D., Shriners' Hospital for Crippled Children, Salt Lake City 3, Utah

William Costen, M.D., 3720 Washington Boulevard, St. Louis 8, Missouri

Eugene A. Foster, M.D., University of Virginia Hospital, Charlottesville, Virginia

Pinckney J. Harman, Ph.D., Department of Anatomy, Seton Hall College of Medicine and Dentistry, Jersey City 4, New Jersey

Charles Henkelmann, M.D., 1703 27th Street, Bakersfield, California

W. S. Hunter, M.D., 4270 Monarch Way, Salt Lake City, Utah

Robert W. Huntington, Jr., M.D., 1830 Flower Street, Bakersfield, California

Mortimer Iger, M.D., 2011 18th Street, Bakersfield, California

John J. Innis, M.D., 914 West Cannon Street, Fort Worth, Texas

Bernard Jacobs, M.D., The Hospital for Special Surgery, New York 17, N.Y.

Malcolm D. Jones, M.D., University of California Medical Center, San Francisco 22, California

Robert D. Larsen, M.D., 76 West Adams, Detroit 26, Michigan

Paul R. Lipscomb, M.D., Mayo Clinic, Rochester, Minnesota

Cedric W. Lowrey, M.D., 622 Lauricella, New Orleans, Louisiana

H. R. McCarroll, M.D., 3720 Washington Boulevard, St. Louis 8, Missouri

Malcolm H. McGavran, M.D., Washington University School of Medicine, St. Louis 10, Missouri

John F. McLeay, M.D., The Creighton University School of Medicine, Omaha, Nebraska

J. L. Magnani, Ph.D., % Department of Anatomy, Seton Hall College of Medicine and Dentistry, Jersey City 4, New Jersey

Edward A. Nalebuff, M.D., 1180 Beacon Street, Brookline 46, Massachusetts

E. D. Vere Nicoll, M.D., 920 High Street, Charlottesville, Virginia

Caesar Orofino, M.D., 1522 North Broadway, Santa Ana, California

Francis X. Paletta, M.D., 634 North Grand Boulevard, St. Louis 3, Missouri

Joseph L. Posch, M.D., 76 West Adams, Detroit 26, Michigan

S. D. Sanwal, M.D., % Department of Orthopaedic Surgery, New York University-Bellevue Medical Center, New York, N. Y.

Richard C. Schneider, M.D., C-5135 Out-Patient Building, 1405 East Ann Street, Ann Arbor Michigan

Edwin R. Schottstaedt, M.D., 384 Post Street, San Francisco 8, California

Donald J. Sheffel, M.D., 1420 Crestmont Drive, Bakersfield, California

Arthur G. Ship, M.D., St. Louis University School of Medicine, Department of Surgery, 1402 South Grand Boulevard, St. Louis 4, Missouri

Herbert A. Spady, M.D., Washington University School of Medicine, St. Louis 10, Missouri

David H. Sutherland, M.D., 595 Buckingham Way, San Francisco 27, California

Alfred B. Swanson, M.D., 313 Blodgett Medical Building, Grand Rapids 6, Michigan

Nahoto Takagishi, M.D., Red Cross Hospital, Lenda-Machi 1 chome, Hiroshima City, Japan

T. Campbell Thompson, M.D., 535 East 70th Street, New York 21, N. Y.

W. A. L. Thompson, M.D., 115 East 67th Street, New York 21, N. Y.

James B. Troup, M.D., Mayo Clinic, Rochester, Minnesota

Benedict R. Walske, M.D., The Creighton University School of Medicine, Omaha, Nebraska

Vallee Willman, M.D., St. Louis University School of Medicine, Department of Surgery, 1402 South Grand Boulevard, St. Louis 4, Missouri

A. Radiograph of area following fenestration and biopsy. Diagnosis, chondrosarcoma.

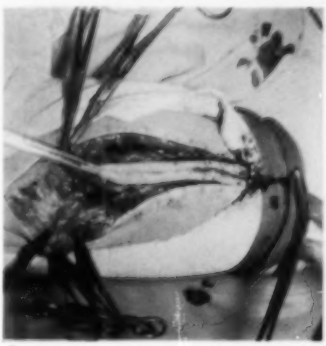
B. Postoperative radiograph: Upper half of humerus has been excised and graft (proximal half of fibula) inserted.

SEGMENTAL BLOCK EXCISION

of upper two-thirds of humerus

Radiographs on Kodak Blue Brand Medical X-ray Film; color pictures on Kodak Ektachrome Film.

Shown on this page, and the next, are the highlights of an unusual procedure in bone surgery. Truly, an interesting, informative presentation! An open invitation to every physician to document his work with "living" photography —photography which will "live" for years to come!



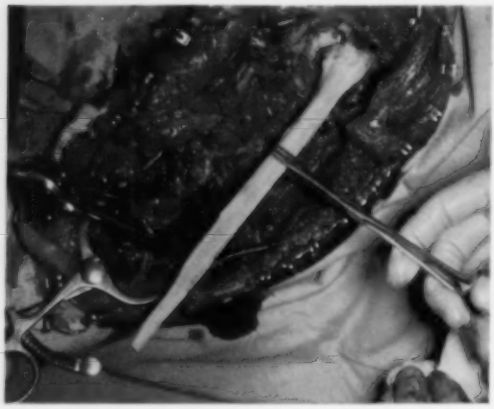
1. Elliptical incision to excise former biopsy wound, left arm. Sterile hose tourniquet at right.

2. Proximal extremity of distal shaft of humerus after transection at junction of lower and middle thirds.

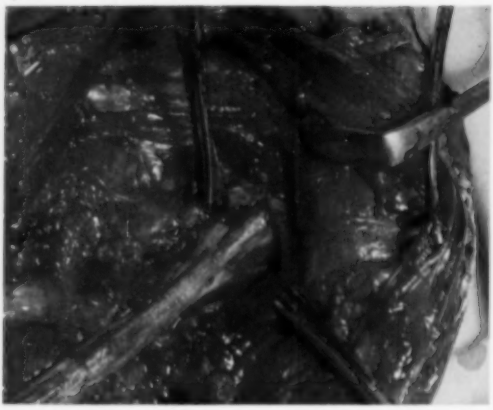
3. Full mobilization of fibula, left leg.

4. Final separation of humerus by division of capsule and musculotendinous cuff.

SEGMENTAL BLOCK EXCISION *(continued)*



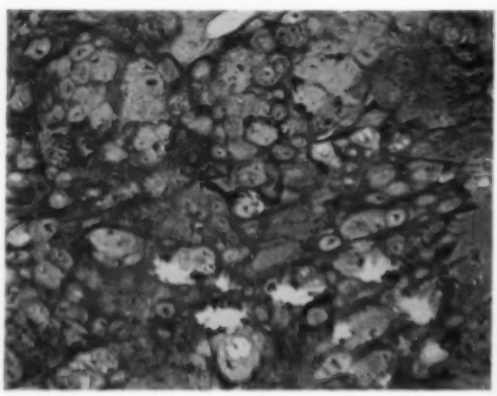
5. Graft held in place against wound of left arm. Distal portion of humerus is at left; glenoid fossa at right.



6. Proximal end of graft attached by suture to short rotator muscles.

7. Distal end of graft now firmly embedded intramedullarly into distal shaft of humerus.

8. Excised proximal portion of humerus with attached biopsy wound removed en bloc.



9. Photomicrograph (intermediate power): Cartilaginous tumor interpreted as enchondroma. On the basis of clinical behavior the final diagnosis was chondrosarcoma.

• **From Kodak come medical x-ray films** —Kodak Blue Brand and Kodak Royal Blue. (Royal Blue, Kodak's fastest x-ray film, is designed to assure minimum exposure for each examination.)

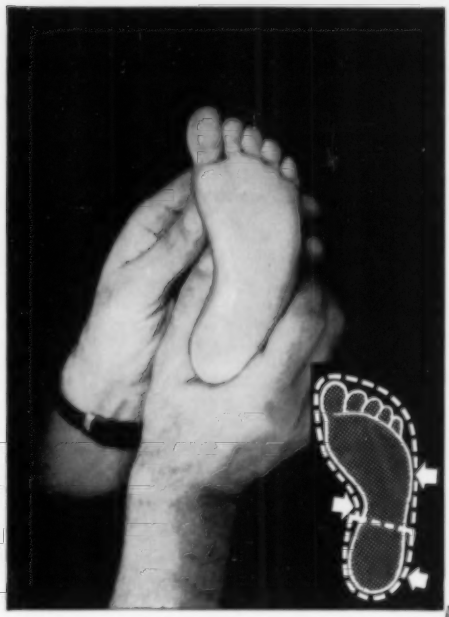
Kodak color materials are available for every photographic purpose: *For miniature and motion-picture cameras*—Kodachrome Film; *for sheet-film cameras*—Kodak Ektachrome Film and Kodak Ektacolor Film; *for roll-film and miniature cameras*—Kodak Ektachrome Film and Kodacolor Film; also Kodak color print materials.

Order Kodak x-ray products from your Kodak x-ray dealer, Kodak photographic products from your Kodak photographic dealer.

***Medical Division,* EASTMAN KODAK COMPANY, Rochester 4, N.Y.**

Kodak
TRADE MARK

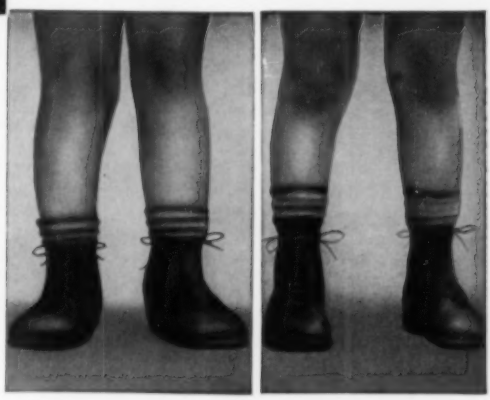
the action of the TARSO SUPINATOR SHOE



. . . swings the hind-foot inward, which induces adduction of the fore-foot, elevates the longitudinal arch, and levels the ankle joint.

When the hind-foot is held in a position of inward rotation, the talo-scaphoid and cuneiform-scaphoid joints will remain locked under weight bearing. The arch will not collapse and the ankle will not roll inward.

Correction is accomplished by the specially shaped last. Medially wedged and extended heels promote better weight distribution. Medially extended counters are used for utmost control.



BEFORE AFTER

The Tarso Supinator shoe is used successfully in treatment of the plano-valgus foot. Pronation is controlled at once. Permanent improvements in walking and in foot posture will generally occur. Patients find Tarso Supinators notably comfortable.

Tarso Shoes are ready-made and are available on prescription from dealers in most cities. Write for catalog and name of nearest dealer.

TARSO SUPINATOR REGUS PAT OFF SHOE

FOR FLAT FEET

M. J. MARKELL SHOE COMPANY, INC.

332 SOUTH BROADWAY • YONKERS, NEW YORK

ORIGINATORS OF TARSO PRONATOR® AND TARSO MEDIUS® SHOES

Tarso shoes have been in use for over twenty-five years.

In answering advertisements, please mention *The Journal of Bone and Joint Surgery.*

The thing
to look for in
Elastic
Bandages
is

E·L·A·S·T·I·C·I·T·Y

AND THAT MEANS TENSOR
WITH THE POSITIVE STRETCH THAT KEEPS ITS SNAP
FOR LONGER LASTING COMPRESSION

Heat stability and strength are important of course. These are requirements, fundamental in TENSOR bandages. Where the brands differ—where the quality shows up—is in the lasting support.

This is where Bauer & Black's many years of specializing in bandages and elastic goods play a key role.

Safe, Comfortable, Conforming

A special weave of highly developed rubber threads gives TENSOR Elastic Bandages sure, even compression over large areas. Self-conforming, they adjust readily and comfortably to swelling. Thin plastic tips eliminate the risk of bulky points—safer and easier to apply.

These are the qualities that spell the difference. TENSOR Elastic Bandages cost no more than any other fine bandage. Yet TENSOR gives you features found in *no* other bandage plus the reassurance that you are treating your patients with the best.

No other elastic bandage costs less per day than TENSOR. By Bauer & Black, of course.

TENSOR®

ELASTIC BANDAGE

Woven with heat resistant live rubber threads

THE KENDALL COMPANY
BAUER & BLACK DIVISION

Maria del Carmen del Valle never heard of Warsaw, Indiana

. . . but Zimmer is a name she knows!

Her doctors, like many throughout the world, put complete confidence in Zimmer internal fixation implants—manufactured exclusively in Warsaw, Indiana, U.S.A. This confidence is founded on experience plus the knowledge that the uncompromising quality of Zimmer products is backed by constant, intensive research.

A. S. Aloe Puerto Rico
P. O. Box 6545
Santurce, Puerto Rico

Zimmer Certified Stainless is made exclusively for Zimmer and must pass rigid tests for corrosion resistance, proper Rockwell hardness and other mechanical properties. Zimmer Certified Stainless steel is truly a highly refined, quality controlled, special breed of stainless steel designed specifically for the manufacture of internal implants.

Barros, Iskin & Cia. Ltda.
Av. Franklin Roosevelt, 115-A
Rio de Janeiro, Brazil

zimmer® ZIMMER MANUFACTURING CO. • WARSAW, INDIANA, U. S. A.

LOOK FOR THE TRADEMARK (Z)

Truform Hinged Kneecaps Model 968 laced front (pictured), Model 969 without lacing, Model 970 without lacing or two encircling straps.

CONTROLLED stability

Circular compression of the entire area covered is readily controlled by adjustment of the lacings . . .

Lateral stability of the joint is effectively controlled by the two leather straps encircling the leg, to which the leather casings of the hinged steel side pieces are joined . . .

Controlled stability is most completely secured with this Truform Hinged Kneecap, another of the anatomically correct and therapeutically sound appliances by Truform.

Truform Anatomical Supports are available to you and your patients only from the Ethical Appliance Dealer.

THERAPEUTIC HOSE

SURGICAL AND POST-OPERATIVE SUPPORTS

CORRECTIVE BELTS AND SUPPORTS

BACK SUPPORTS

Many other types, in many models.
Write for your copy of "The Red Book."

TRUFORM

anatomical supports

3960 Rosslyn Drive, Cincinnati 9, Ohio
BRANCHES: New York and San Francisco

In answering advertisements, please mention *The Journal of Bone and Joint Surgery.*

Precise Positioning and Positive Fixation—

with AMERICAN-Albee

ORTHOPAEDIC *and* FRACTURE TABLE

● Acknowledged as the most versatile in its field, the American-Albee Orthopaedic and Fracture Table enables the orthopaedic surgeon to achieve "perfect positioning" of short, tall, obese and even infant patients . . . easily and rapidly. It is designed to accommodate closed fracture reductions as well as the increasing demands of complex orthopaedic surgery. Thus, to orthopaedists the world over, the name American-Albee identifies the table of choice for this comprehensive branch of medicine.

Ideal complement to this improved table is the American DV-22 Major Surgical Light . . . a new concept in easily maneuverable illumination . . . cool, shadowless, color-corrected . . . intensity to 10,000 foot candles *from a dual source.*

● *Write for Fracture Table Brochure TC-100R and Major Light Catalog LC-121R.*

Offices in 14 Principal Cities

AMERICAN STERILIZER

ERIE • PENNSYLVANIA

'TiS STERiLE!

'TAiN'T STERiLE!

The nice old lady who scored her pie crusts "TM" and "TM" ('Tis or 'Tain't Mince) never knew which was which. So it is with "homemade" petrolatum gauze...there's always the question of sterility. That's why most hospitals specify 'Vaseline' Sterile Petrolatum Gauze U.S.P. This label insures the absolute sterility that is difficult to attain in hospital-made gauze.

Available in 6 sizes

IN DISPOSABLE PLASTIC TUBES

½" x 72" selvage-edged strips, 6 to box

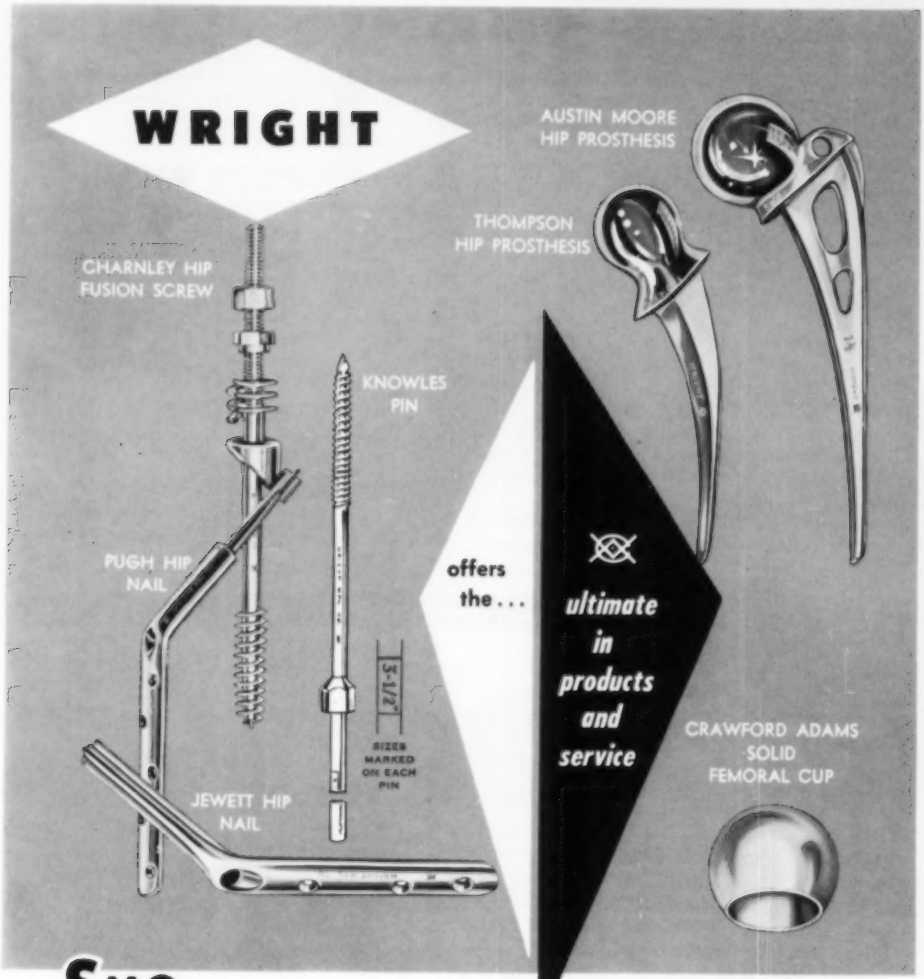
IN HEAT-SEALED FOIL ENVELOPES

3" x 3" pads, open to 3" x 9" strips, 6 to box
1" x 36" strips, 6 to box
3" x 18" strips, 6 to box
3" x 36" strips, 6 to box
6" x 36" strips, 6 to box

PROFESSIONAL PRODUCTS DIVISION
Chesebrough-Pond's Inc., New York 17, N. Y.

VASELINE® STERILE PETROLATUM GAUZE

'TiS STERiLE!



with **SMO** type 316

STAINLESS STEEL DROP-FORGED IMPLANTS

Smo Type 316 Stainless Steel is developed particularly for internal fixation appliances by the steel industry in cooperation with the Bureau of Standards and American Academy of Orthopedic Surgeons and Military Surgeons. This material being inert, exists on the friendliest terms with bone, body fluids and soft tissues. All WMC Stainless Steel Implants are Zyglo tested under the most rigid conditions and electropolished and packed in polyethylene envelopes to assure the surgeon of complete metal surface cleanliness. All WMC products are of highest quality and are unconditionally guaranteed against defective workmanship and materials. Write to Dept. F-2 for further information.

WRIGHT MANUFACTURING COMPANY • 880-882 ADAMS • MEMPHIS, TENN.

PRESTON *A Complete Line* **FOR PHYSICAL THERAPY AND REHABILITATION**

REHABILITATION: Bicycle Exercisers; Restorator; Walking Parallel Bars and Exercise Staircases of various designs; Posture Mirrors; Gymnasium Mats; **Shoulder Wheels** with or without height adjustment; **Elgin Progressive Resistance Exercise Units;** Quadriceps Boots; Dumbbells; Chest Pulley Weights; **Standing (Tilt) Tables; Stryker Turning Frames.**

HAND THERAPY DEVICES: Kanavel Table; Manuflex; Wrist Exercisers; Complete Line of **Bunnell Splints;** Theraplast.

TRACTION: Many types of Cervical and Pelvic Traction Sets; **Hausted Tractionaid.**

HYDROTHERAPY — ELECTROTHERAPY: Whirlpools; Paraffin Baths; **Hydrocollator;** Ries Moistaire; **Medcolator** and other Low-Volt Generators; Infrared Lamps; Bakers; **Birtcher Ultrasonic Generators.**

Everest & Jennings Wheelchairs; Commodes; **Walkers** and Walking Aids for every need; **Hydraulic Patient Lifters;** Largest selection of **Treatment Tables.**

Complete Line of Cerebral Palsy Equipment — Speech Therapy — **Self Help Devices for the Handicapped.**

JUST OFF THE PRESS!

THE ALL-NEW PRESTON CATALOG #1065

- Features *today's most complete line* of Equipment for Physical Therapy and Rehabilitation.
- 208 profusely illustrated pages . . . over 2500 product listings, including many new items of interest to you.
- Your one dependable guide in ordering Physical Therapy Equipment.

SEND FOR YOUR FREE COPY TODAY

We supply *ALL EQUIPMENT* for setting up a complete Rehabilitation Program. Suggested layouts and equipment lists are available to you through *OUR FREE PLANNING SERVICE.*

J. A. PRESTON CORP., 175 FIFTH AVENUE, NEW YORK 10, N. Y.

NEW **ELGIN EXERCISE CHAIR FOR PROGRESSIVE RESISTANCE EXERCISES**

Here is an ENTIRELY NEW EXERCISE UNIT, clinically proven to be extremely beneficial during early treatment of the hemiplegic patient (reciprocal motion exercises for arms and legs). The NEW ELGIN EXERCISE CHAIR also provides excellent treatment for many other cases such as polio, arthritis, and the orthopedic patient.

May be used in the physical therapy department, hospital ward, or for home treatment.

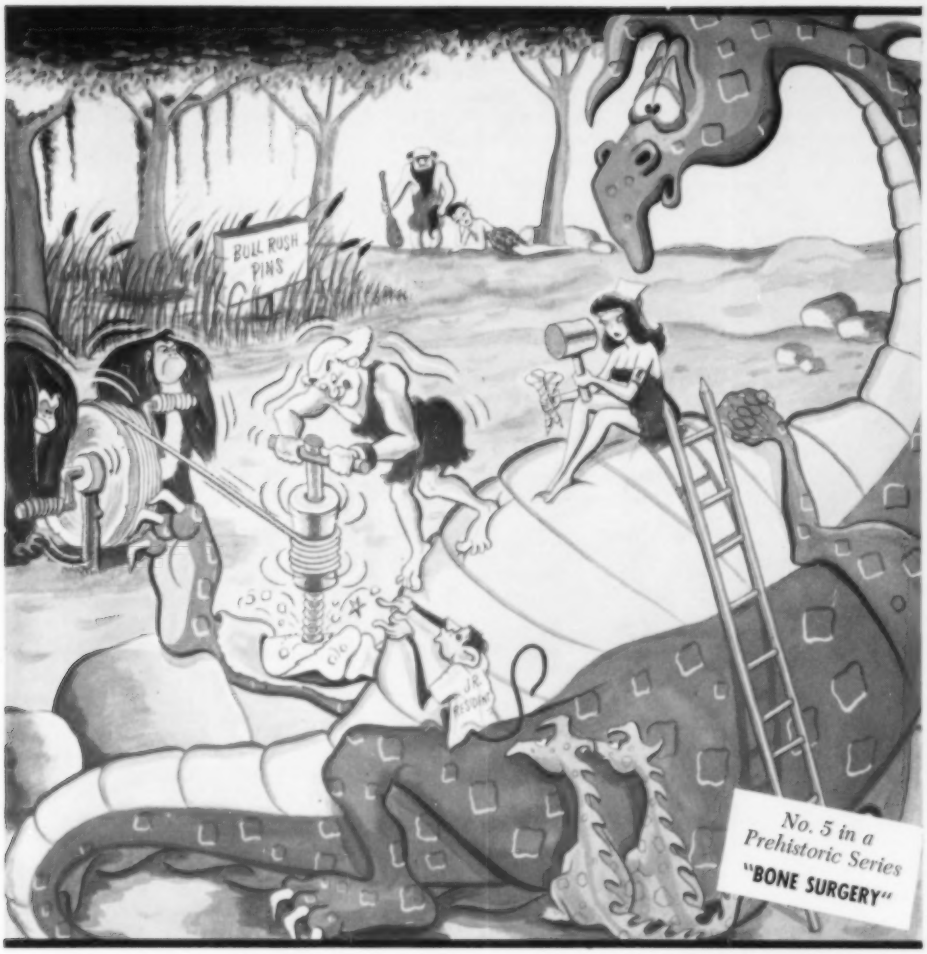
Complete brochure illustrating the many exercises possible with this revolutionary new unit will be sent on request.

Elgin offers the most complete line of Progressive Resistance Exercise Equipment. Write today for free catalogues.

SOME FEATURES

- Sturdy . . . Safe Comfortable
- Requires Minimum Amount of Space
- Correct Mechanical Position While Exercising
- Excellent for Resistive, Assistive, or Reciprocal Motion Exercises

Elgin **EXERCISE APPLIANCE CO.**
P. O. BOX 132 ELGIN, ILLINOIS



Reprints suitable for framing available upon request.

Today's concept in bone Surgery . . .

Stryker **COLORGUIDE DRILL and SCREW DRIVER**

These attachments for the Electro-Surgical Unit have been designed to ease the surgeon's task of drilling, driving screws and inserting pins and wires. Color coded for automatic determination of depth of hole and length of screw.

This light weight handpiece is geared to slow speed and operates not only the Drill and Screwdriver, but also a ⅜" Jacobs Chuck.

Available on 30 day trial.

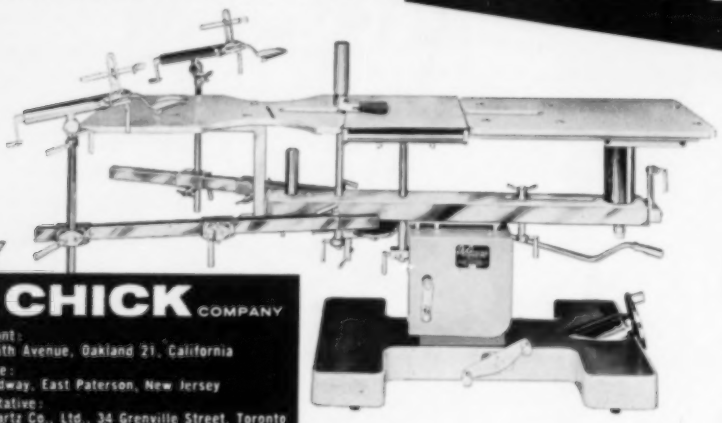
SURGICAL AND HOSPITAL EQUIPMENT

Stryker Orthopedic Frame Company

420 ALCOTT STREET • KALAMAZOO, MICHIGAN

Flexibility Insures Maximum Efficiency

Flexibility is the keynote of Chick DVHI Orthopedic and Surgical Table. Featuring variable height, it employs a self-contained hydraulic unit with built-in safety factor. Table tilts laterally and offers Trendelenburg position of 15°, **reverse Trendelenburg of 7½°**. Other outstanding features include **new foot-locking device for positive table positioning** and carriage-mounted Chick Transverse Cassette Tunnel. DVHI is ideal for all Orthopedic surgery, most general surgery, and all cast work. Write today for information.



GILBERT HYDE **CHICK** COMPANY

Main Office and plant:
821-75th Avenue, Oakland 21, California
General Sales Office:
5 Broadway, East Paterson, New Jersey
Canadian Representative:
J. F. Hartz Co., Ltd., 34 Grenville Street, Toronto

Manufacturers and Distributors of
Hospital Orthopaedic and Fracture Equipment.

THE RUTH JACKSON COLLAR

The Ruth Jackson collar, providing maximum occipital support, will maintain, with a high degree of comfort, the flexed position with chin tucked in, recommended by Ruth Jackson, M.D., F.A.C.S., in her book "The Cervical Syndrome."

Clinical experience discloses the analogy between the cervical and lumbar spines as to pains originating from pathological conditions or trauma without actual vertebral fracture. Often treatment with extension or hyper-extension may be actually detrimental and stabilization in the normal or in the flexed position may be indicated. In all positions except full extension, failure to provide support, not only to the chin, but also laterally and to the occiput will result in inadequate stabilization.

THE EXO-STATIC COLLAR

(completely redesigned)

The Exo-Static collar, while it may be adjusted for full extension, may also be lowered to a point of slight flexion and provides stabilized support, not only to the chin, but laterally and to the occiput, *automatically adjusting to the proper occipital height corresponding to the extension required.*

FLORIDA MANUFACTURING CORPORATION

BOX 449 • DAYTONA BEACH, FLORIDA

Reprint from Chapter on Treatment in "Cervical Syndrome" available on request

PARAFLEX

Chlorzoxazone*

rapidly relieves both pain and stiffness . . . facilitates recovery

PARAFLEX provides effective skeletal muscle relaxation for 6 hours with a 1- to 2-tablet dose. It relieves painful muscle spasm and improves function in a wide variety of traumatic, arthritic, and rheumatic disorders. PARAFLEX is especially valuable when used in conjunction with physiotherapy and other rehabilitative procedures. Side effects are rare, almost never require discontinuance of therapy.

Dosage: ADULTS—1 to 2 tablets three or four times a day.
CHILDREN—½ to 2 tablets three or four times a day, depending on age and weight.

Supplied: Tablets, scored, orange, bottles of 50. Each tablet contains PARAFLEX, 250 mg.

*U.S. Patent No. 2,895,877

McNEIL

McNEIL LABORATORIES, INC • PHILADELPHIA 32, PA.

330A60

IN WHIPLASH INJURY

The Straight Last... friend to all young feet!

It's no wonder doctors praise the versatility of this foot covering. Basically can be worn by a normal foot, yet the Junior Arch Preserver shoe built on a true straight last may be fitted with whatever wedging and pads you indicate for your youthful patient's special prescription. All Junior Arch Preserver shoes are constructed by Medic craftsmen to the most exacting standards . . . in a wide variety of lasts that make it easy to meet each child's shoe needs. They're the finest value in children's shoes . . . safe and sound to prescribe and recommend to your patients.

For the name and address of the store nearest you carrying Junior Arch Preservers, write today to

Junior ARCH PRESERVER Shoes by MEDIC

MEDIC Shoe Manufacturers, Inc.
1212 Wood Street, Philadelphia 7, Pa.

The complete line of feature shoes for children that doctors recommend

NO MORE

because

VITAGENIC

THE PRESCRIPTION-BUILT
EXTRA-FIRM MATTRESS
NEEDS NO
INTERPOSED BOARD

Physicians and orthopaedic specialists know that a bedboard—even one that is interposed in a mattress—is only an attempt to correct a structural weakness and inadequacy in the mattress itself. The VITAGENIC by AIRELOOM requires no "make-shift" additions.

THE VITAGENIC is a mattress and box spring combination made according to the exact specifications of registered orthopaedic specialists. It is an important—almost essential—adjunct to your plan of treatment for pain of backache or sacroiliac injury. You prescribe the exact degree of firmness necessary for your patient as well as any other features required for treatment or comfort.

CURLED HAIR FOR RESILIENT FIRMNESS

Firm body support without undue pressure on nerve points or interference with circulation.

HAND-STITCHED SAG-FREE SIDEWALLS

Sag-free edges allow patients with back injuries to get in and out of bed with less effort and greater stability. 12% more usable sleeping area.

THE VITAGENIC IS GUARANTEED FOR 15 YEARS

For full details on the prescription-built VITAGENIC, contact:

Aireloom
BEDDING COMPANY
1119 Westminster Ave., Alhambra, Calif.
created by King Karpen—established 1951

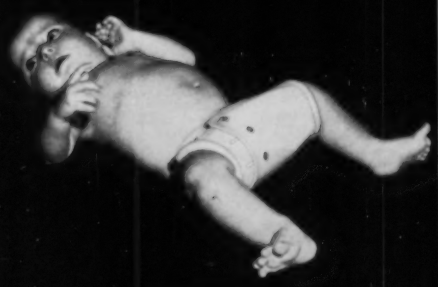
Richards

CRAIG ADJUSTABLE HIP SPLINT

(Patent Pending)

For the treatment of:

CONGENITAL DYSPLASIA AND DISLOCATION OF THE HIP



In the treatment of congenital dysplasia and dislocation of the hip under two years, an ideal splinting position is with the hips at 90° flexion and 90° abduction.

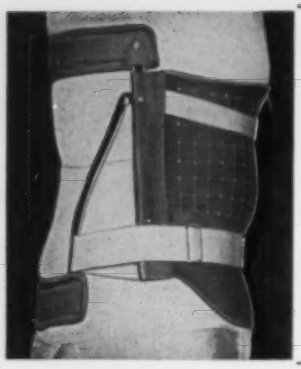
Tubular shaped when on the patient, the Craig Adjustable Hip Splint holds the hips comfortably in this correct position without rigid or bulky immobilization. It is impervious to water, thus completely sanitary. Constructed of frosty white plastic with plastic covered foam rubber binding to prevent irritation. The splint retains the diapers, eliminating the need for safety pins. Two snap-button fasteners makes diaper changing easy.

By a simple "button-hole" adjustment, the splint is suitable for all infants from birth to two and one-half years.

WRITE FOR FULL INFORMATION

Richards MANUFACTURING CO.

756 Madison Avenue, Memphis, Tennessee



WILLIAMS LUMBO-SACRAL FLEXION BRACE

Orders filled at the request of members of the profession only

Measurements: 1. Chest (about 4" below nipple line); 2. Waist (at navel line); 3. Pelvic (½ distance between greater trochanter and crest of ilium); 4. Seventh cervical spinous process to the prominence of Coccyx.

ALL ORTHOPAEDIC APPLIANCES

MILLER BRACE CO.

3902 Gaston Avenue Dallas, Texas

For prompt service use our P. O. Box 7902

Custom Built: Braces—Surgical Supports—Splints—Arch Supports—Folding Wheel Chairs—Aluminum Adjustable Crutches—Airfoam Head Halter Sets—Airfoam Rib Binders—Canes, Etc.

A SELF ADJUSTING HIP-NAIL WITH ALL THE FEATURES–PLUS FRICTIONAL ADJUSTMENT

the 'KEN' Hip Nail

(PAT. APP'D. FOR)

For femoral neck, inter and subtrochanteric fractures

Engineered To Satisfy The Following Requirements:

1. FURNISH A **MORE ADEQUATE FIXATION.**
2. ALLOW **IMPACTION.**
3. REDUCE POSSIBILITY OF **PENETRATION OF THE HIP JOINT.**
4. PREVENT **DISTRACTION.**
5. **SIMPLIFY INSTALLATION.**
6. FURNISH **STRENGTH.**
7. COMPENSATE FOR **VARIABLE FRICTIONAL RESISTANCE.**
8. SIMPLIFY AND **REDUCE INVENTORY REQUIREMENTS.**

THE 'PATENTED' LONG TUBE AND PLATE IS A FEATURE FOUND ONLY IN THE KEN HIP-NAIL. IT PROVIDES STRENGTH AND ELIMINATES FRICTION CAUSED BY SIDE THRUST. ALLOWS IMPACTION. THE LENGTH OF THE TUBE CONTAINS THE 'SLIDEABLE' NAIL PORTION EVEN WHEN FULLY CONTRACTED. THIS ELIMINATES THE POSSIBILITY OF THE NAIL PROTRUDING INTO SOFT TISSUE.

AVAILABLE AT YOUR NEAREST SURGICAL SUPPLY DEALER

THE NAIL AND DRIVER ARE CANNULATED

EXCLUSIVELY MANUFACTURED BY

KEN STANDARD CORP.

EVANSVILLE, INDIANA

UNDER ONE OR MORE (PATS.), (PATS. PEND.), and/or (LICENSES)

FOR TREATMENT OF SPASTIC CASES • CEREBRAL PALSY • STROKE • POLIO • HAND INJURIES

General Electric Co. Silicone

BOUNCING PUTTY

As a "trial order" send $2.00 for one $2.85 jar

does not harden

lasts indefinitely

and can be autoclaved.

S. R. GITTENS, *Distributor,* 1620 Callowhill St., Phila. 30, Pa.

For Congenital Dislocation of the Hip—**ORDER**

FREJKA

ABDUCTION PILLOW SPLINTS

with the new Wet-Proof pillow

3 SIZES:

Small—6" pillow splint (up to 4 months)
Medium—9" pillow splint (4 to 8 months)
Large—12" pillow splint (over 8 months)
Available in Pink, Yellow & White

PHONE—Midway 4-6874

MINNESOTA ORTHOPEDIC SERVICES
1963 Carl Street **St. Paul 13, Minn.**

PRICE

With Extra Halter $12.50

POSTPAID

LIST OF ADVERTISERS

September 1960

	Page
Acme Cotton Products Co., Inc.	31
Aeroplast Corporation	35
Aireloom Bedding Company	58
C. H. Alden Shoe Company	22
Alexander Industries, Inc.	61
American Sterilizer Company	51
Austenal, Inc.	20, 21
Bauer & Black, Division of the Kendall Company	6, 7, 48
The Berivon Company	40, 41, 42, 43
Bowen & Company, Inc.	38
S. H. Camp and Company	4
G. W. Chesbrough Co.	25
Chesebrough-Pond's, Inc., Professional Products Division	52
Gilbert Hyde Chick Company	56
DePuy Manufacturing Company, Inc.	18
Eastman Kodak Company	45, 46
Elgin Exercise Appliance Co.	54
Florida Brace Corporation	30
Florida Manufacturing Corporation	56
Freeman Manufacturing Company	28
S. R. Gittens	60
Hack Shoe Company	37
J. E. Hanger, Inc.	8
Herbst Shoe Manufacturing Company	5
House of Bidwell, Inc.	61
Ken Standard Corp.	60
Lederle Laboratories, Division of American Cyanamid Company	36
McNeil Laboratories, Inc.	15, 39, 57
M. J. Markell Shoe Company, Inc.	47
Medic Shoe Manufacturers, Inc.	58
Medical Research Specialties	24
Merck Sharp & Dohme, Division of Merck & Co., Inc.	23
Miller Brace Co.	60
Minnesota Orthopedic Services	61
V. Mueller & Co.	34
Orthopedic Equipment Co.	29
Orthopedic Frame Company	16, 55
OTC Division, Surgical Appliance Industries	62
J. A. Preston Corp.	54
Richards Manufacturing Company	44, 59
I. Sabel, Inc.	32
Schering Corporation	19
Chas. A. Schmidt Surgical Instrument Company	14
Spencer, Incorporated	33
E. R. Squibb & Sons	17
Truform Anatomical Supports	50
Wallace Laboratories	13, 26, 27
Wright Manufacturing Company	53
Zimmer Manufacturing Company	9, 10, 11, 12, 49

LIGHT

Satin Finished Duralumin

—

Brace and Corset Comb.

—

Taylor Chairback or Williams Braces

—

One-Day Service

—

Write for Brochure

Alexander

INDUSTRIES, INC.

373 EAST BROAD ST., DEPT. 12, COLUMBUS 15, OHIO

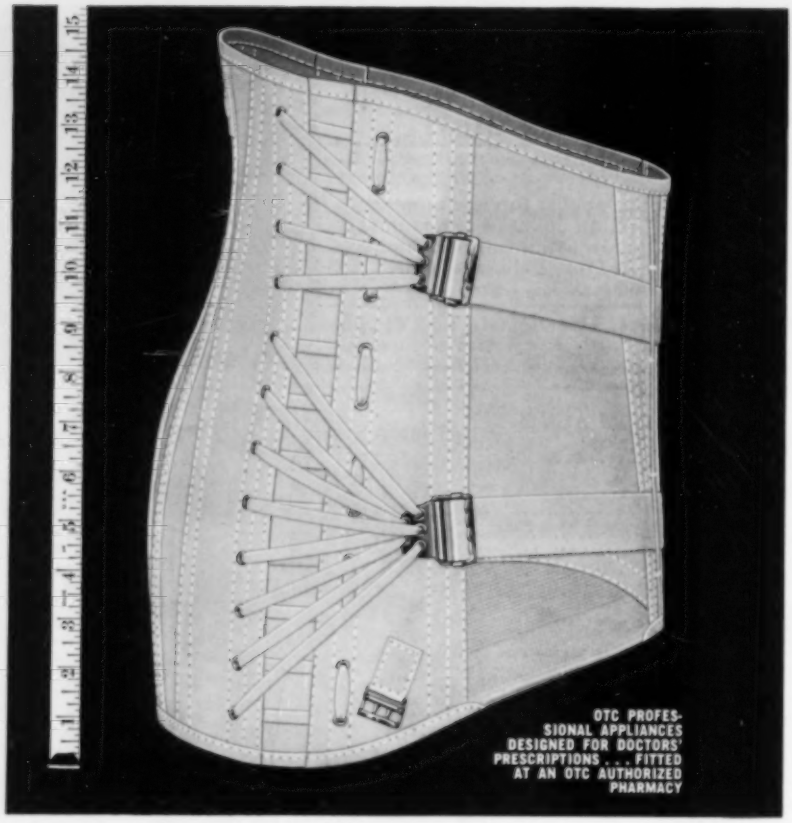
To serve your complete needs in ORTHOPEDIC, PROSTHETIC and SURGICAL APPLIANCES

house of BIDWELL inc.

535 N. 27th Street
Milwaukee 8, Wis.

1134 Regent St.
Madison, Wisconsin

EXTRA DEEP



15″ back assures effective control

Here is the sacro-lumbar support particularly designed for stabilization of the entire lower spine . . . OTC Model 829-HS.

The deep 15″ back will cover as high as the eighth dorsal vertebra in the average patient, and as high as the tenth in even the very tall. In the back, multiple flexible stays and two rigid shaped steels deliver stabilizing support to the entire lower spine. Two sets of pull straps control the encircling pressure.

Whatever OTC Support or Orthopedic Appliance you prescribe, you and your patient can always expect these benefits:

- **Therapeutically Sound**, designed and constructed to aid you in securing the desired therapeutic result.
- **Expertly Fitted** by OTC-trained fitter.
- **Conveniently Available** on your prescription at your OTC authorized pharmacy.

WRITE for your copy of the reference folder on OTC Professional Appliances, designed for doctors' prescriptions. ASK for your OTC authorized pharmacy's name.

Orthopedic Therapeutic Corrective

OTC *division of surgical appliance industries, inc.*

DEPT. A ERIE AVE., CINCINNATI 9, OHIO Branches: New York, San Francisco, Ottawa

Supports • Orthopedic Appliances • Surgical Hosiery • Specialties

In answering advertisements, please mention *The Journal of Bone and Joint Surgery*.

The Journal of Bone and Joint Surgery WELCOMES ARTICLES WHICH CONTRIBUTE TO ORTHOPAEDIC SCIENCE FROM ALL SOURCES IN ALL COUNTRIES

- Articles are accepted only for exclusive publication in *The Journal of Bone and Joint Surgery*.
- Publication does not constitute official endorsement of opinions presented in articles.
- Articles published and their illustrations become the property of *The Journal*.

WHEN YOU SUBMIT AN ARTICLE PLEASE SEND:

1. THE ORIGINAL MANUSCRIPT AND, IF POSSIBLE, DUPLICATE MANUSCRIPTS COMPLETE WITH ILLUSTRATIONS. THE EXTRA COPIES WILL GREATLY ACCELERATE EDITORIAL DECISION. Keep a copy. Manuscripts of accepted articles will not be returned.
2. BIBLIOGRAPHY, alphabetical, of references made in text *only*. Please refer to bibliographies in this copy of *The Journal* and follow style exactly.
3. LEGENDS for all illustrations submitted, listed in order.
4. ILLUSTRATIONS
   a. *Black and white glossy prints* of photographs.
   b. *Original* drawings or charts.
   c. *Magnification* of photomicrographs.

NOTES ON PREPARATION OF MANUSCRIPT

- Manuscripts must be typewritten, double-spaced with wide margins.
- Write out figures under 100 except percentages, degrees, or figures expressed in decimals.
- Direct quotations should include exact page numbers on which quotation appeared in book or article.

NOTES ON PREPARATION OF ILLUSTRATIONS

- Number all illustrations.
- Indicate *top* plainly.
- Write author's name on the back of each one.
- Put dates or initials in *Legends*, not on prints.
- Send prints unmounted or mounted only with rubber cement. Paste or glue will damage prints.
- Drawings, charts, and lettering on prints should be done with black India ink. Use white India ink on black backgrounds.
- Make lettering large enough to be read when drawings are reduced.
- When submitting an illustration which has appeared elsewhere give full information about previous publication, credit to be given, and state whether or not permission to reproduce has been obtained.

COPYRIGHT

Material appearing in *The Journal* is covered by copyright. As a general rule permission will be given to reputable medical journals to reprint anything in these pages, if permission is first obtained from *The Journal* and if the material used is properly credited to *The Journal*.

MIMEOGRAPHED BROCHURE. "Writing for *The Journal of Bone and Joint Surgery*" WILL BE SENT ON REQUEST.

Manuscripts submitted for publication in the AMERICAN VOLUME should be sent to The Editor, *The Journal of Bone and Joint Surgery*, 8 The Fenway, Boston 15, Massachusetts.
Manuscripts submitted for publication in the BRITISH VOLUME should be sent to The Editor, *The Journal of Bone and Joint Surgery*, 82 Portland Place, London, W. 1, England.

THE RUMFORD PRESS
CONCORD, N. H.